

# WAR MEDICINE

## *A Symposium*

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## MILITARY SURGERY

By COLONEL GEORGE DE TARNOWSKY, *Med. Res.*

Since the end of World War No. 1 important changes have occurred which affect the duties and functions of the military surgeon. Paramount among these changes must be mentioned:

1. Increasing range of artillery fire.
2. Increased effectiveness of air forces.
3. Mechanization of war effectives resulting in a marked increase in mobility.

These changes have resulted in:

1. Increasing the distance from the firing line of all medical units.
2. Increased rapidity in the evacuation of all wounded from front to rear.
3. Decrease in the type and amount of surgery permissible in advance surgical formations.
4. Evacuation hospitals will probably never again be allowed to be set up and function at or even near a railhead.
5. With a rapid rolling up of enemy forces, i.e., rapid and successful advance of our own troops, mobile surgical units may still prove invaluable.

This short review of military surgery cannot include services rendered in base hospitals where equipment, surroundings, and absence of danger closely simulate conditions found in any modern civilian hospital. In the combat zone the medical officer immediately finds himself confronted with an environment and a class of traumatic lesions more or less foreign to him. He is no longer able to choose his own conditions but has to make the best of those in which his lot is cast. He soon learns that, to quote a French military surgeon: "One does what one can, where one can, when one can, how one can." No longer allowed to consider the case of the individual soldier as paramount, his treatments must invariably be subservient to the military necessities of the moment. The front line medical officer will have to forego the use of most of the drugs, instruments and appliances he has been accustomed to using in civil practice. Light equipment of all front line formations, lack of time, and urgent necessity of rapid evacuation of all transportable wounded to evacuation hospitals compel regimental, battalion and division surgeons to give simple but adequate lifesaving treatment to large numbers of casualties in the shortest space of time possible without any attempt to complete operative procedures, the latter only being possible in evac-



uation hospitals or—if the terrain and battle conditions permit—in mobile surgical units. The training received in civil practice would naturally prompt any surgeon to give immediate and thorough attention to penetrating lesions of the abdomen. In the combat zone this would be a grave error unless a mobile surgical unit has been allowed to attach itself to a field hospital. Such operations, requiring considerable time, equipment and the services of three surgeons, including the anesthetist, would necessitate neglecting a large number of minor injuries and result in a failure to promptly return to the firing line men essential to victory. Military necessity compels him therefore to simply cleanse and dress the severely wounded and evacuate them as rapidly as possible to the evacuation hospital. It cannot be strongly enough emphasized that the two essentials of war surgery must consist in (a) rendering the greatest number of fighting men fit for duty on the firing line within as short a time as possible and (b) rapidly evacuating to the rear, by previously selected routes all men who are hors de combat. While the selection of evacuation routes may not always be a satisfactory one, a careful reconnaissance on the part of the corps surgeon may enable the latter to select side roads not used by oncoming troops. The very bad psychic influence produced upon reserve troops who are hurrying up to action by the sight and sound of severely wounded men, cannot be overemphasized. Every effort should be made to spare them from such scenes. The business of the front line surgeon is to speed casualties to the rear as fast as he and transportation facilities permit. Of the wounded in detail he can see little, he sees them only en masse. It therefore becomes axiomatic that the slightly wounded should be given early and thorough treatment at the front, as they remain potential fighting units. In all probability, divisional or corps stations for slightly wounded will again function. The three factors, lack of time, inadequate equipment (including surroundings) and military necessity, must force the front line surgeon to accept this viewpoint—or run the risk of being transferred to a labor battalion! It is well to remember also that in warfare nothing is fixed or unchangeable. Medical arrangements may have to be devised anew for each action, they will vary with the plan of battle and usually must be modified as the battle develops. Alternative sites and routes should always have been thought out, and the surgeon should never forget to notify both front and rear of any changes he has made.

The sine qua non of a good soldier is to forget—to submerge in a large degree—his individuality as promptly and as thoroughly as possible. We all become cogs in a vast war machine each cog must work



harmoniously to its utmost capacity toward a common goal—victory! Esprit-de-corps means prompt, unhesitating, often unthinking obedience to higher authority; may we all attain that very essential spirit!

This discussion does not permit giving a detailed description of the diagnosis and treatment of all types of war wounds. I shall therefore take up a few outstanding problems confronting the military surgeon at the front.

Shock will continue to tax our efforts because its presence so frequently modifies the end-results of surgical repair. Please remember that the degree of shock present in any given case may be all out of proportion to the wound or wounds found on the soldier. There are many contributing and accentuating factors to be taken into consideration, such as pain, cold, hunger, heat, thirst, fatigue, and loss of sleep. The importance of recognizing these secondary factors was most dramatically demonstrated during World War No. 1. In the spring and summer months of 1918, when the weather was comfortable and our soldiers were fresh from training camps, shock only occurred among the severely wounded. When the rainy season opened and our troops were fighting in the Argonne sector, with transportation bogged up, inadequate food and shelter, loss of sleep, cold and hunger became almost major factors in the production of shock, regardless of the type of injury received. Without academically detailing the various theories of shock, we must admit that it is a disturbance of functional equilibrium characterized clinically by reactions of depression which may be severe enough to prove fatal. It is often associated with severe hemorrhages or precocious toxemias, increasing the difficulty of appreciating the relative importance of each etiologic factor. Physiologists believe that the rapid repetition of painful impulses causes exhaustion or inhibition of the medulla. These impulses may be entirely psychic and we must recognize the possibility of true nervous shock. Four vital processes are notably depressed.

Subnormal temperature

Feeble, rapid and irregular pulse

Shallow and sighing respiration

Low blood pressure

Regardless of the etiologic factor or factors there ensues a dilatation of capillaries and a pooling of blood within them. An abnormal permeability of endothelial walls develops with escape of plasma into the loose cellular tissues and concentration of blood corpuscles within the vessel walls. Emphasis should be directed to this last statement. In shock it is only the blood plasma and not the blood corpuscles which



passes by diapedesis into the loose cellular tissues, hence a blood count will reveal a normal or even an increased number of red cells. In hemorrhage, on the other hand, whole blood is lost through torn vessel or vessels, and if considerable loss has occurred, the number of red corpuscles will be found to be decreased.

**Prophylaxis** Shock will be prevented or minimized by decreasing painful stimuli by

- 1 Immediate immobilization of fractures and physiologic rest of all injured tissues

- 2 Adequate doses of morphine, provided an accurate diagnosis of the lesion or lesions is not thereby masked

- 3 Rapid accurate and gentle handling of tissues during any and all operations

Shock will be relieved by

- 1 Heat to the body, including the extremities

- 2 Hot drinks (unless contra indicated by the presence of visceral lesions)

- 3 Lowering of the patient's head (except in lesions of the head, heart or lungs)

- 4 Checking of hemorrhage. In cases of internal bleeding diagnosed preoperatively or suspected, shock should not be treated until the surgeon is ready to seek and check the source of the hemorrhage, i.e., he should treat shock and hemorrhage simultaneously. The mistake, frequently fatal, of stimulating a patient in shock without having previously ruled out hemorrhage is so often made that a few remarks on elementary physiology may be permitted. In shock, particularly when associated with hemorrhage, the cardiovascular system is at its lowest ebb. The pulse is rapid and thin, blood pressure is below normal, respirations are rapid and shallow. Blood issuing from a torn solid viscus or a lacerated vessel flows more and more slowly and clotting eventually occurs even in a closed wound. The bleeding ceases and remains in abeyance as long as the patient remains in shock. Unwise cardiac stimulation increases heart action and raises arterial tension. The primary clot is loosened, secondary hemorrhage occurs and the already depleted soldier expires.

- 5 Intravenous injection of a 6% gum acacia solution is of great benefit in shock not associated with hemorrhage. Normal saline is both illogical and harmful because the fluid escapes through the dilated capillaries and further increases the pooling of serum in cellular spaces. Gum acacia molecules are too large to escape through the vessel walls. It is true that the use of an impure product caused some alarming re-



actions in 1918; in its present standardized form it can be safely used.

6. In evacuation hospitals, blood transfusions, given at the time of operation, will displace gum-acacia solutions. Whether blood-banks can be safely used in evacuation hospitals or possibly stored blood-plasma as recently advocated, is still a moot question. There certainly would be the same objection to the use of plasma alone in shock that we have noted in saline solutions.

7. Absolute psychic and physiologic rest after any war trauma or subsequent surgical intervention.

### **Hemorrhage**

Injuries involving the main trunks in the neck, thorax or abdomen and those of the main vessels of the liver, spleen, or kidneys are usually fatal before any surgical help can be given. Hemorrhage from any of the larger peripheral arteries may be profuse enough to endanger life. Inasmuch as the wounded soldier has to be evacuated from the aid station to the field hospital and thence to the evacuation hospital and the duration of evacuation may fluctuate within wide limits, there are only two safe methods of checking a severe external hemorrhage, *i.e.*, ligature and forcipressure. Tight packing of a wound and the use of the tourniquet should never be resorted to except in dire necessity; if done at all, the fact should be noted on the field tag, giving the date and hour at which it was done. Both litter bearers and ambulance drivers should be instructed to loosen the tourniquet for a few minutes at least every hour, reapplying it if the hemorrhage starts up again. It seems hardly necessary to remind you that tight packing of a wound favors the development of gas gangrene, while a tourniquet left in situ over several hours will result in death of a limb. In the field hospital tight gauze packing and tight bandages should be removed and, if time permits, the bleeding vessel should be sought for, ligated, and the wound lightly covered with gauze and bandage. If the wound involves a limb, immobilization of same is of paramount importance before further evacuation. Immobilized muscles cease to contract; non-immobilization or inadequate immobilization permits spasmodic retraction of muscles, thus tending to carry infected particles beyond the wound itself—another potent factor in the production of gas gangrene. A complete revision of the wound, with debridement when indicated should only be attempted in an evacuation hospital. Regardless of the type of open wound inflicted on a blood vessel, the clinical manifestations of hemorrhage will only vary in quantity depending on the degree of gaping of



most important of all on the amount of resistance to the outpouring of blood offered by the surrounding tissues

The cardiodynamic picture following the rupture of an artery is dominated in the initial stages by the effects of reduced venous return. Initially diastolic pressure decreases more than systolic the pulse pressure is greater and the peripheral pulse acquires a collapsing characteristic. The following mechanism tend to some degree to compensate for the sudden loss of blood (1) diversion of blood from capillary pools (2) contraction of the spleen and (3) dilution of blood by resorption of lymph. The tendency for arterial pressures to fall rapidly as a result of hemorrhage is partly counteracted by (1) an increase in depth and rate of respiration which tends to favor the return of blood to the right heart (2) an inhibition of the vagus center causing an increased heart rate and (3) a stimulation of the vasomotor center causing a constriction of peripheral blood vessels. Every hemorrhage except one coming from a very large vessel has a natural tendency to be checked long before the loss of blood becomes dangerous. The duration of bleeding depends not so much upon the size of the vessel wounded as on the facility with which an efficient clot forms over the opening and on the type of wound open wounds exposed to the air greatly facilitating the phenomenon of blood clotting. In closed wounds the size of the hematoma will to a large extent depend on the anatomic barriers tending to circumscribe the effusion. Closed wounds involving the dome of the liver are rarely fatal because the bleeding is arrested by pressure of the diaphragm above and the falciform ligament laterally. The same is true of kidneys lung parenchyma muscle fascial planes or subcutaneous connective tissue. It thus becomes easy to understand why retroperitoneal splenic or mesenteric wounds necessarily demand immediate surgical intervention.

The cardinal symptoms of hemorrhage are a rapid soft pulse a low blood pressure and obvious anemia. Excessive thirst and air hunger are common. If the bleeding is severe and intra abdominal fluid may be detected in the flanks and shifting dullness may be demonstrated by turning the patient from side to side. The patient may state that he feels something hot running inside him. We have frequently noted this particular symptom which is hard to explain on physiological grounds for the temperature of blood urine or gastrointestinal content is that of all subcutaneous structures. It is futile to attempt to determine the probable type of intra abdominal trauma by observing the wounds of entrance and exit. Bullets and shell fragments often ricochet and multiple visceral lesions are almost the rule. A bayonet wound on the other



hand, gives one a fair index of the locale of the trauma. The finding of hematuria, bloody feces or a mucobloody rectal discharge or a frothy hemoptysis are important diagnostic signs. Early vomitus, early abdominal distention usually indicate a hollow viscus lesion.

Prognosis should always be guarded and usually kept in abeyance for at least twenty-four hours. It not only depends on early intervention when indicated, but principally on the number and severity of visceral lesions, ease with which hemorrhage has been checked and the possibility of complicating peritonitis or visceral necrosis.

Basic indications for immediate operation are clinical symptoms pointing to progressive intra-abdominal hemorrhage or hollow viscus penetration. Repeated blood examinations at short intervals are invaluable. Perforation of a hollow viscus demands immediate intervention. With a suspected wound of a solid viscus, but without symptoms of severe hemorrhage, an expectant attitude should be adopted. Most of these cases recover without intervention. If the hemorrhage has been severe enough to produce a picture of frank anemia, the best working rule is to operate if the patient is seen very early but to watch and observe for a few hours if the patient is seen six or eight hours after the injury. If then the anemia is not apparently progressive, one should not operate, for the hemorrhage has to all intents ceased and laparotomy will cause a renewal of bleeding with a probable fatal result. On the other hand, if there are signs of progressive hemorrhage, the abdomen should be opened at once. A good working principle is to operate if reasonable doubt exists regarding a hollow viscus lesion for the mortality of such an operation is exceedingly low when no visceral lesion is found. Two general rules may be followed to aid the army surgeon in his choice of an incision: (1) Plan the incision to meet the visceral lesion suspected. (2) Avoid if possible the site of entrance and exit wounds in order to diminish the liability to wound infection. Always make the operative wound sufficiently ample to insure unhampered exploration. An 8-10 inch long incision avoids evisceration of intestines during closure of the abdominal wall. For all middle and lower abdominal operations the paramedian incision gives the best results because no nerve fibers are cut and postoperative herniation is almost unknown. For injuries to the liver or spleen, without traumata to hollow viscera the transthoracic extrapleural incision facilitates exposure and treatment of these two solid organs. This incision is based on the anatomic fact that a thoracic incision beginning at the eighth costal cartilage in the parasternal line and running obliquely downwards, outwards and backwards to the tenth rib in the mid-axillary line and twelfth rib in the



scapular line absolutely avoids the pleural sinus. A lumbar incision is only indicated in kidney lesions or for evacuation of retroperitoneal hematomata. In the presence of free intra abdominal hemorrhage a suction apparatus should be used if uncontaminated by gastro intestinal contents the blood should be rapidly centrifuged and the plasma either injected intravenously or poured back into the peritoneal cavity just before closing.

Many valuable minutes will be saved if the surgeon has acquired a definite routine for his examination of the abdominal contents. Our preference is to begin at the right upper abdominal quadrant palpating the right kidney then passing a hand over the dome of the liver and examining its anterior and inferior surfaces. A finger is next introduced through the foramen of Winslow in order to palpate the head of the pancreas and first two portions of duodenum. Stomach and gastrotocolic omentum are then inspected for perforations or lacerations. The spleen and left kidney come next. By lifting up the great omentum and transverse colon and passing an index finger from right to left under the colon the first loop of small intestine encountered is at the ligament of Treitz. From that point on successive loops of jejunum and ileum are lifted up carefully examined and rapidly replaced in the abdomen by an assistant. Having arrived at the ileocaecal valve the entire colon is inspected to its pelvic end. Visualization of the bladder completes a system of inspection which makes it impossible to miss any lesion. Any area where trauma is encountered is temporarily tamponed. Perforations are clamped off with intestinal clamps and the perforation is closed with a hemostat. Mesenteric vessels if torn are clamped and the involved loop of intestine observed for viability or non viability. Especially in the presence of multiple intestinal lesions is it poor judgment to repair each lesion when found as the delay involved increases the danger of peritoneal contamination. With bleeding tamponed and leakages clamped the surgeon can proceed with the permanent care of the lesion or lesions encountered. Wounds of the liver are tamponed the end of the gauze brought out through a right lumbar stab wound. It should remain in situ for five to seven days being progressively withdrawn. With the exception of small tears which merely require tamponing a laceration extending to the hilus of the spleen usually involves one or more of the splenic vessels and necessitates a splenectomy. Care must be taken not to injure the tail of the pancreas or greater curvature of the stomach while ligating the splenic pedicle. In poor surgical risks the pedicle can be clamped with 8 in. forceps which are then covered with vaseline coated gauze and left in situ for three to five days.



Lacerations involving the mesentery at right angles to the long axis of the intestinal tract seldom require more than ligation of the arterial or venous branch and closure of the rent. Where there is complete detachment of a segment of bowel from its mesentery and the proximal portion of the mesentery has had its main artery torn, the prognosis as to viability of the segment is bad. Collateral circulation is notoriously poor and the surgeon must decide between an immediate resection and end-to-end anastomosis in good risks and exteriorization of the involved loop in bad risks. In any case the torn vessel must be double ligated even if bleeding has ceased. Unless the renal artery has been severed, hemorrhage from either kidney will rarely warrant a primary nephrectomy; tamponing will usually suffice as far as immediate treatment is concerned. Hemorrhage from a perforating wound of the bladder is never serious per se, but immediate repair will prevent deep cellulitis or pelvic peritonitis. Bleeding from a wound of the pancreas is not alarming, but escape of pancreatic ferments into the peritoneal cavity represents one of the hardest problems in surgery. The sheltered position of this organ makes it almost impossible to be wounded without adjacent injury to the stomach, duodenum, transverse colon or spleen. An early pre-operative diagnosis of pancreatic injury is impossible. When discovered, one may—rarely—attempt to suture the rent. Usually the surgeon will be limited to tamponing of the injury, tubal and vaseline-gauze drainage and protection of the abdominal wall by means of zinc oxide ointment generously spread over the entire abdomen.

Blood transfusion, 5-10% glucose solutions intravenously, heat to the body and complete physical and psychic rest are all valuable adjuvants. Repetition may seem uncalled for, yet we would again remind army surgeons never to stimulate a patient with a suspected or possible internal hemorrhage until the latter has been controlled or is about to be controlled on the operating table. Stimulate while you operate!

In military surgery the onset of septicemia may be so rapid that, even when the primary focus of infection is discoverable and removable through debridement, drainage or relief of tension, little or no improvement may follow. The outcome will depend almost entirely on the rapidity with which the wounded soldier can marshal his own defenses. It is in such cases that therapeutic attempts to lower fever are to be deplored. From a clinical viewpoint there can be no question but that fever is our best index of the virility of reaction on the part of the patient against bacterial infection. Predisposing factors which tend to reduce the protective forces of nature, such as excessive fatigue, loss of sleep, hunger, as well as prolonged operations, rough handling of tissues,



to the touch. Sudden chill, rise in temperature and pulse rate, as well as leucocytosis vary within wide limits and depend entirely on the degree of resistance marshalled by the individual.

Active treatment consists in the main in changing a deoxygenated lacerated wound into one obtaining free access to oxygen. Multiple incisions, opening of intermuscular septa, thorough debridement of all devitalized or dead muscle tissues and, if obtainable in advance formations, continuous irrigations with hydrogen peroxide—the one positive means of bringing oxygen to the utmost depths of the wound. In spite of recent encouraging reports, specific treatment by vaccines is still in the experimental stage and we should not abandon the simpler methods enumerated which have proven their value. You will, of course, have noted that I have omitted blood counts, smears of wound secretions or the use of the X-ray. By the time a wounded soldier suffering from a type of wound favoring the onset of gas gangrene has reached an evacuation hospital where, for the first time, laboratory facilities are available, his fate has been decided unless front-line surgeons have given him early, simple but energetic prophylactic treatment.

Tetanus will also claim the immediate attention of front-line surgeons. Fortunately, antitetanic serum—750-1500 units—has proved its prophylactic value. In addition to the serum, all punctured wounds should be freely opened before the wounded soldier leaves the field hospital.

A few words about maggots may not be out of place. We had many maggot-treated wounds during the Argonne offensive; I mean, of course, that maggots found their way under bandages and dressings, not that we placed them there! These wounds were the cleanest we ever saw. It is to be deplored that Dr. Baer, who popularized the maggot treatment of osteomyelitis after the armistice, should have laid so much stress on the so-called sterilization of maggots before placing them in the wound. Maggots only devour dead cells, are not toxic and their wings do not have to be brushed off with an antiseptic solution!

Immediate immobilization of all fractures will prevent or lessen pain during transportation, keep involved muscles flaccid and minimize the danger of septicemia and gas-gangrene. An immobilized muscle does not contract; hence cannot carry infected material beyond the site of the wound. In the process of immobilization of a shattered bone, care must be taken not to impair the circulation of the limb, i.e., allowance must be made for the increase in the circumference of a limb caused by loss of blood in and around the wound. Such wounds should be well padded and circular bandages put on lightly and not tightly.

Of greatest importance during a battle is an adequately staffed and



competently organized section in all evacuation hospitals. Experience gained during a tour of inspection of British and French casualty clearing stations and H O T s (Hopital Origine 1 tapes) in 1917 enabled us to work out a system which proved such an invaluable time saver that it would seem worth while to describe some of its details. Those who might wish to study the system in its entirety will find my paper on Convoys and Their Care in the October 19 1918 number of the *Journal of the American Medical Association*. During an important engagement the admitting squad plays a very outstanding role. One sergeant and from four to six privates selected for their clerical qualifications will suffice for ordinary convoys; this number may have to be doubled or trebled if the casualties are pouring in by the hundreds. Rapidity and accuracy are both essential; ambulances must be promptly discharged and blankets pillows and stretchers returned in order not to hinder transportation problems. A varying number of stretcher bearers must also be assigned for duty during the emergency, as well as a squad of orderlies to wrap up and make out receipts for clothing and personal belongings. The hospital organization must be made elastic enough to meet all contingencies; rigidity must give way to flexibility if one does not wish to see the hospital grounds littered up with a tangled mass of ambulances stretchers and walking wounded—precious hours wasted because sudden shifting of duties and details have not been foreseen and worked out. Walking cases line up in front of the clerk's table give up their field cards receive a ward ticket and pass on rapidly to the buffer. Stretcher cases are laid in rows in the admitting tent and the clerks pass rapidly from one to the other recording all necessary data in duplicate for all urgent cases. As fast as the duplicate clinical record is filled out with the ward number on it the stretcher bearers carry each patient to the receiving ward returning litter pillow and blankets to the ambulance waiting outside. While the admission of patients is normally included among the duties of the officer of the day we found it necessary to appoint a special admitting officer for this extremely important and difficult task. He not only supervises the paper work but acts as a triage officer. Not only must he be a surgeon of quick and mature judgment but he must also constantly have in mind or on paper (a) the relative technical value of the surgical teams (b) the special surgical teams on duty (c) the hours of the different surgical shifts and (b) the available beds in each surgical service. From a rapid examination of the general appearance of a given casualty plus written indications on the field card he decides as to its disposal. When in doubt he waits until the soldier is in bed in the receiving ward and



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then makes a thorough examination before coming to a final conclusion. With a sudden convoy of several hundred casualties arriving within a few hours it stands to reason that some of the wounded will have to wait several hours before their turn in the operating room comes. The admitting officer must decide on the order of preference. Those patients requiring immediate limb or life-saving intervention must reach the operating room immediately, regardless of the order of their admission or of the surgical service to which they are assigned. In times of stress, all surgical cases must be pooled. Space does not permit me to describe cleansing and delousing methods. All urgent cases are directed to the X-ray room, where they are X-rayed, all fractures recorded and foreign bodies localized. Shock cases are given immediate attention. As soon as the disposal of a convoy has been determined, the admitting officer—now become director of surgical material—takes position near the operating room in order to keep in constant touch with the stretcher bearers, X-ray and anesthetizing rooms, thus insuring a constant stream of wounded toward the operating room and preventing undue congestion at any point.

I have already mentioned the buffet. Regardless of the severity of their wounds, nine out of ten wounded soldiers clamor for food before they are out of the ambulances. We gave them hot tea, chocolate or cocoa, sandwiches, hash or some other hot dish. Abdominal cases were the one exception. While admitting the fact that the giving of nourishment to a patient who may shortly afterward require anesthetizing presents certain esthetic disadvantages, I have yet to see any harm caused by this war custom. When one has seen hundreds of wounded men eating their fill at the buffet and then deloused, washed up and clothed and in clean pajamas, fall into their beds and into sound slumber from which they awaken a few hours later strengthened and refreshed, ready for their operative ordeal, there can be no further doubt regarding the best procedure to follow. Food they should have, civilian surgical notions to the contrary notwithstanding. A wounded soldier is a disabled athlete, not a sick man!

For a 2000 bed evacuation hospital, five tents or barracks, approximately 6x18 yards, will be required. Of these, one is used for admission, one for a buffet and undressing room, two for stretcher cases and one for a bathing room.

The great problem in an evacuation hospital is to operate properly and rapidly on a large number of patients in a short space of time—the shorter the better for each patient. Much useful time can be needlessly wasted in the operating room, waiting for patients. If one repre-



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sents as 100 the total expenditure of time in a given surgical case—from the time the patient arrives in the ward until he returns thereto from the operating room—this number can ordinarily be thus subdivided

Undressing and cleaning of patient	30
Preparation of operative field in ward	10
Waiting for turn in X ray room and fluoroscopy	10
Anesthetizing patient	10
Operation	20
Dressing bandaging immobilization and removal of patient from operating room	20
	<hr/>
	100

A properly organized admitting tent and competent director of surgical material will easily quadruple the operative output of a surgical team—an all important item during a heavy engagement

As one looks back on the successes or failures incurred while in military service certain axioms stand out and as an old war veteran who was fortunate enough to satisfy the demands made on him I make bold to pass them on to the present group of officers on whose shoulders will fall the task of carrying on where we left off

1 Avoid criticism of the actions or orders of a senior officer, he is probably in possession of special information

2 Be a father to your men

3 The beau ideal of any military unit is one in which officers and men alike perform their respective duties not in a spirit of fear fear of reprimand or punishment but because they have become imbued with the proper esprit de corps are proud of their outfit and determined to give the best service possible no matter what demands are made on them

4 From the youngest shavetail to the commanding officer self criticism should frequently be resorted to We shouldn't expect the men under us to perform duties or carry out maneuvers with which we are not familiar you cannot impart knowledge which you yourself do not possess Authority over your men will not be lessened but enhanced when you show a willingness to help them even manually, when you find them in difficulties General Frank Parker retired illustrated the importance of looking after the welfare and comfort of the men by recounting the following incident On inspection tour one day in France he spied a soldier limping along the road Telling his driver to stop the staff car the general walked back to the soldier and asked him why he was limping On being told that his shoes were too small



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General Parker had the soldier get in the staff car beside him, drove to the nearest Q.M. advance depot and personally saw to it that proper shoes were found and exchanged for the misfit ones. Did he leave the man at the depot, to walk back to his outfit? Indeed not; back they went in the staff car to the soldier's destination! No wonder that the troops commanded by so humane and understanding an officer were able to write some of the most brilliant pages of the American Expeditionary Forces!

5. The keystone of efficiency in the army is loyalty, loyalty to the army and to the medical profession, loyalty to one's unit and commanding officer, loyalty to one's juniors.

6. In the heat of battle, when officers of all units, combatant as well as non-combatant, are loaded with emergency details, the surgeon can and often must make his own decisions. Artillery fire may suddenly make his aid-post, collecting station or field hospital untenable; evacuations may become impossible over pre-arranged routes owing to destruction of same or clogging up by oncoming troops or supplies; a sudden retreat may bring his outfit too close to the firing line. He has no time to send back a runner for new orders but must issue them himself—and be prepared to defend his decision!



# SURGICAL PRINCIPLES IN DIVISIONAL MEDICAL UNITS

By COLONEL C MAX PAGE, DSO, MS, FRCS

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The work of divisional medical units under conditions of active service is mainly aimed at the efficient evacuation of casualties. It has become clear in the present campaign that a smooth and rigid scheme of treatment and evacuation from aid posts to casualty clearing stations as was possible in 1917-18 cannot be achieved. The medical services in the field must adapt their activities to events, and though it is impossible to forecast the circumstances under which individual units will work, the general principles of wound treatment should form the background of their action in relation to the individual wounded man. There is no doubt that the treatment he receives in the zone in question has a great influence on his subsequent condition, and an attempt will be made below to define what should or should not be done with a wounded man in regimental or field ambulance posts.

We started this war with a clear idea of the ideal wound treatment: this was founded on the experiences of 1914-18, and was to some degree coloured by reports on Spanish practice in their civil war. Since then experiences with our Expeditionary Forces and at home have done little to alter the established principles though they have brought to light the value of the sulphonamide group of drugs in prophylaxis. Moreover, there has been activity on the research side both in relation to these drugs and into the value of antisera for anaerobic infections. The importance of fluid replacement in the treatment of shock has become fully recognized and the provision of preserved blood or a substitute has been put on a sound basis.

## Importance of Early Operation

Whatever adjuvants to wound treatment we may now possess nothing has lessened the proved importance of early operation for the majority of the wounded if serious infection is to be avoided. The operation in general will be one of debridement or the establishment of drainage, in accordance with the time lag imposed and the surgical conveniences available. Primary repair is aimed at only for intra-abdominal injuries and those of the chest wall and skull. Primary suture of a somatic wound is not advisable except in very carefully selected cases. The ideal time for operation after the man has been injured cannot be defined with absolute precision. It is generally recognized that the period during which a radical excision or repair operation is likely to be satisfactory



is within at most twenty-four hours of injury. Subject to the necessary period of resuscitation most authorities would reduce the ideal time-lag to twelve hours.

Our organization in the forward area is based, therefore, on getting the seriously wounded into the care of a surgical centre with the minimum of delay. The term "surgical centre" is used to imply any organization where formal surgery and the full process of resuscitation can be carried out. The difficulties in conforming to this ideal under the varying conditions of modern war are only too patent. We have to admit this handicap and aim at adaptability and elasticity in this matter as in other spheres of Army activity.

### **Treatment in Forward Units**

The following may be laid down as the procedures to be carried out for the wounded at the aid post before transfer to the surgical centre:

1. A simple dressing of adequate size is applied to the wound if this has not already been done.

2. If the patient has not already received it, A.T.S. (3,000 units) should be given and the fact notified on his field medical card. The employment of anti-gas-gangrene serum at this stage may be of value, but a decision as to its general use has not been arrived at. Sulphanilamide may be administered to the more seriously wounded, especially in cases in which fractures are present. It should be given by the mouth, a 2-gramme dose to start with and 1 gramme at four-hourly intervals subsequently up to a total of about 20 grammes. A note as to the time the treatment started and the dosage given should always be entered on the man's documents for future guidance. The question of packing the wound with sulphanilamide is referred to below.

3. *Shock*.—The first need of the wounded man is for rest, warmth, relief of pain, and drink. Simple though these demands are in quiet periods, in forward units they cannot always be completely satisfied under conditions of activity. When achieved they go far to bring a man out of primary shock. Transfusion of serum or plasma will of necessity be limited by the conditions of the aid post and other circumstances. In general, it may be said that the transfusion of a pint of serum or plasma at this stage should be reserved for serious fracture cases or for those in which a severe haemorrhage has been controlled by ligature. For a serious burn similar treatment will sometimes be advisable before evacuation, but it is evident that the storage of the necessary material and the conditions for the proper administration of a transfusion will exist only in the larger aid posts.



The following notes are concerned with the treatment of special conditions

### Fixation of Fractures

Satisfactory fixation of fractures before evacuation is of the first importance if secondary wound shock and increased local damage are to be avoided. For fractures of the thigh and in the region of the knee the Thomas splint is of the greatest value. It should be applied in accordance with the recognized method, over the clothes with the boot and sock still in place. Traction is exerted through a clip or skewer attached to the boot or by binding the foot to a foot plate. Traction should not be severe, nor should it aim at a complete reduction of any overlap of the fragments which may be present. A splint with a large sized ring must be used for these cases and therefore the result of forced traction is to push the ring up into the femoral angle, producing a condition that is both uncomfortable for the patient and liable to produce a pressure sore. The tension applied should only be sufficient to stabilize the fragments. The ring of the Thomas splint, when too large, can be to some extent stabilized by packing between the upper part of the thigh and the outer section of the ring. Judicious suspension of the ring from a suspension bar attached to the stretcher will also have the same effect.

<sup>1</sup> *Fractures of the tibia and fibula* may be treated in the same splint. As a rule little or no traction is required but control of the rotation of the lower fragment should be obtained by binding the foot to the foot piece. In fractures of the lower half of the leg a simple box splint with a foot piece is, I think, preferable. This can be made from Cramer wire splinting or, if this is not available from boards or Gooch splinting. A similar arrangement should be employed for the splintage of injuries about the ankle or foot.

*In the upper extremity* fractures of the humerus in the proximal half of the bone, and including injuries to the scapula are best fixed by binding the arm to the side with a pad placed between the arm and the chest wall, the forearm is supported by a sling. If the fracture is in the lower half of the bone or about the elbow joint the use of a posterior splint extending from the shoulder to the hand is desirable the elbow being set at about a right angle. This splint is most conveniently made from Cramer wire splinting. If it happens to be available a plaster-of-Paris slab instead of the wire splint will serve even better, but there must be no question of applying a complete encircling plaster bandage in this phase. Fractures of the forearm, wrist, and hand should be immobilized on a section of Cramer wire splinting bent at a right angle to hold the



elbow. It should be noted that fixation of fractures in this stage aims at immobilization rather than rectification of position. It will be sufficient if the limb is aligned in its splint in approximately the normal position. Tight bandaging, especially of the forearm and about the elbow, should be avoided.

*Fractures of both lower and upper jaws* can for the purposes of early transport usually be adequately fixed with the four-tailed bandage. If there is a tendency for the tongue to fall back owing to complete destruction of the symphysis, a stitch or two should be used for either fixation or traction. A feeding-cup with a rubber tube extension on the spout will facilitate feeding. If possible the man should be transported in the sitting position.

*Spine.*—It has become customary to advise the transport of spinal injuries in the prone position. This position is very uncomfortable and distressing for a stretcher journey of any length. Moreover, it renders access for catheterization impossible without considerable disturbance. The theory supporting this practice is that extension of the spine is thereby maintained, the position of the head is maintained, and the tendency to reduce ankylosis is prevented. On preventing vertebral displacement, the prone position certainly has the advantage of preventing the formation of dorsal pressure sores, though not those on the ventral aspect. It is clear that missile wounds of the spine, whether associated with cord symptoms or not, are not subject to this argument. The same may be said of impacted flexion fractures. It is doubtful if the position is of much importance in the case of fracture-dislocations provided that gross flexion of the spine is not allowed to occur. It is therefore advised that spinal injuries should be transported in supine position. The man should be lifted by three persons, one of them taking care to support the spine at about the level of the injury in such a way as to prevent flexion. On the stretcher the lumbar curve is maintained by a small cushion or folded blanket. For cervical injuries extension is sufficiently maintained by a similar arrangement placed just above the shoulder level. In spinal injuries and wounds in which the cord or cauda has been involved the important point in early treatment is the avoidance of pressure sores and infection of the bladder. Pressure sores on the heels are less likely to form if sock and boot are left on, unless the latter are wet through. If available an air ring should be put under the buttocks. When retention of urine is present a gentle attempt at expression should be made; if this fails and the man is very uncomfortable catheterization may be carried out, but only if it can be done with aseptic precautions. If the case has to be retained for some days or if the period of transport is long, it will be well to tie the catheter in (Taylor, 1941).



## War Medicine

*Ribs*—If only a few ribs are broken the disturbance necessary for proper strapping should be avoided unless dyspnoea is extreme and the man is clearly unfit for transport. When many ribs are staved in it is best to strap the chest, completely encircling both sides. This fixation of the lower part of the chest will enforce diaphragmatic breathing, but it reduces the dyspnoea resulting from irregular chest movements.

### Other Special Conditions

*Amputations*—Primary amputation in the forward area should only be undertaken when the lesions of the soft parts are so gross or the damage to the main vessels is so complete that survival of the distal part is out of the question. If evacuation is good even when these conditions are present operation should be deferred until the surgical centre is reached so that a more formal procedure can be there carried out than is usually possible in an aid post. It is said that the development of secondary wound shock can be checked in such cases by the application of a tourniquet immediately above the wound.

*Chest Wounds*—Wounds in this area largely require more than a surface dressing unless an open pneumothorax or sucking wound is present. In this latter event it is important to close the opening effectively. Suture with this in view should not be carried out unless complete wound excision can be coupled with it. A large greased pad and covered with mackintosh tissue should be strapped over the opening (Barrett, 1910). Elastoplast will be most satisfactory for the purpose, but ordinary adhesive tape will serve. The strapping should overlap and extend over the whole pad. Occasionally an early pressure pneumothorax may be met with. Cyanosis and dyspnoea together with displacement of the apex beat and sometimes the trachea will enable a diagnosis to be made (Sellors 1941). When it is recognized it should be relieved by needle puncture at once.

*Abdominal Wounds*—In the ordinary way the wounds will be protected and the patient marked for early evacuation to the surgical centre. Morphine should be given in those cases in which diagnosis of perforation of the gut is evident from the position of the wound or from the clinical signs. No attempt should be made to return prolapsed viscera or omentum; they should be covered with a normal saline pack or plain dressing and bandaged, a note being made of the state of affairs on the F.M.C.

*Head Injuries*—A simple protective dressing only should be employed, even when there is prolapse of brain. A note as to the mental



state of the patient and a record of the pulse and condition of the pupils or any paralysis which may be present should be made on the F.M.C.

*Burns.*—The treatment of burns in the initial phase is directed to preventing shock, which may prove fatal. If, however, the burn is of such a size as not to endanger life the main consideration is quick healing and the restoration of function. The danger to life from extensive burns is best treated by some method of surface coagulation. Tanning has proved the most satisfactory in this respect. The tanning is perhaps best effected with tannafax jelly or the application of compresses wrung out in 2% tannic acid. The latter method of application is most convenient in cases to be evacuated shortly. Smaller burns, and any burns of the face and hands, should not be tanned; they should be powdered with sulphanilamide and then covered with vaselined lint or gauze. No attempt at surgical cleansing is made. There are several pastes on trial for application under these conditions, but it cannot yet be said that any have proved their superiority to the simple method suggested.

*Haemorrhage.*—As a serious problem haemorrhage does not appear as often in aid posts as one would expect from a perusal of first-aid treatises. No doubt if a major vessel is torn open a man dies before aid can be given, and he does not reach the aid post. If a medium-sized vessel is divided completely it has considerable capacity of retraction, and in the condition of shock which is produced by the injury self-sealing will very likely occur. When bleeding is obviously continuing from a wound an attempt should be made at the dressing station to control the bleeding-point with a ligature or forceps. If a tourniquet has been applied it is most undesirable to continue its use for longer than is necessary. In a large proportion of cases in which a tourniquet has been applied in the field haemostasis would have occurred without its use, for it takes place after the tourniquet has been in position for half an hour or so. For haemorrhage from minor vessels firm pressure exerted by a pad bandaged in place, coupled with recumbency, will often suffice for control.

*Priority in Evacuation.*—When evacuation is normal and the journey to the surgical centre can be effected in about an hour abdominal injuries should have precedence. Fractures and sizable retained foreign bodies should come next, and chest and head injuries last. If the pressure of casualties is very great this order will clearly have to be altered, and the alteration must be determined by the medical officer on the spot, since he has a knowledge of the local conditions and surgical possibilities.

*Isolation of an Aid Post.*—When evacuation is impossible and an



aid post is isolated and therefore saddled with the responsibility for the wounded over possibly a period of several days, it is clear that an attempt should be made to produce the conditions of a surgical centre. In fact, this will not often be practicable on account of the lack of personnel and of the necessary amenities. Formal or radical operations for abdominal wounds will seldom be carried out, and the same may be said for chest and head injuries. The surgical treatment of open fractures will be directed to effecting free drainage rather than radical wound excision. Amputations should be carried out for gangrene or for local infections which may threaten life.

*Pansement d'Attente*—The main efforts of available personnel should be directed to the prophylactic use of sulphanilamide for all serious wounds—or if circumstances permit all wounds. This treatment should be made effective as soon as possible. From 5 to 20 grammes should be introduced into each wound according to its size, a total of 40 grammes should not be exceeded in any individual. Enlargement of the wound may be necessary to give complete access. Foreign bodies which have been located and are easy to remove should be extracted at this stage. The powder should so far as is possible, be brought into contact with the whole wound surface or track, it should not be tightly packed in. An insufflator if available may be used but it would appear that introduction with a small spoon of known capacity is more convenient. If instead of powdered sulphanilamide the tablets are used, the latter should be crushed before introduction in order to facilitate absorption by the tissue fluids. The prophylactic use of the drug by mouth as detailed above should be reserved for cases in which the development of serious infection is deemed probable. missile fractures and irregular retained foreign bodies are instances which would come into this category.

### Summary

The above is a brief outline of the surgical principles which should determine our treatment of the wounded man in the forward area together with an attempt to summarize practice. In war any set plan can seldom be carried through in every detail. We should have a clear conception of the ideal at which we aim and in action do our best to attain it despite unforeseen difficulties and inevitable handicaps.

I should like to acknowledge my indebtedness to Brigadiers F. Laing and E. M. Cowell and to Colonels J. Weddell and L. Colebrook for useful suggestions and advice in the preparation of this discussion.



## *Surgical Principles in Divisional Medical Units*

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# WAR WOUNDS

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It will not profit us to discuss the classification of war wounds as to source site or size except in general terms. The current casualties are from bomb fragments and machine gun bullets in contrast to those caused by shrapnel grenades and rifle fire so familiar in World War I. Nor is there special clinical gain by classification in terms of penetrating perforating tangential or other types of war wounds.

The essentials are to combat the *three horsemen of trauma* namely, *shock hemorrhage and infection*. Shock and hemorrhage are best defeated by such surgical ammunition as external heat, fluids and the sovereign power of whole blood or liquid or dried plasma. Before World War II is won my belief is that stored blood will be in the form of capsules or tablets and perhaps even some modification permitting the use of animal blood already endowed to offset the prevailing organisms of the germ infested terrain now actually world wide.

The treatment of the wound itself has two main objectives one to prevent infection the other to promote healing. We know that organisms survive only in the presence of dead or dying tissue. If we can have live tissues we are assured of dead germs irrespective of the source site or size of the wound. Further we know there are two phases in our combat one is the *contamination* the other the *infection* phase of any wound. Hence the time element in our fight is important. Long ago we learned that any trauma treated early usually meant victory but if treatment lagged we yielded to complications that often meant defeat. This time element leading to victory is within the first six hours post trauma the Golden Period. Wounds treated then are in the *contamination phase* treated thereafter they are in the *infection phase*.

The basic elements in wound treatment may be said to be (1) The *time element*—within six hours post trauma (2) the *cleansing element*—soap and water and more soap and water until the parts are cleansed after the manner of preoperative cleansing of our hands (3) the *excising element*—debridement. This means the removal of all damaged tissue by non sacrificial excision until three criteria are attained (a) the parts look healthy (b) bleeding is present from the excised edges and (c) muscle contracts. This process is not in terms of amount of tissue removed it may mean one sixty fourth of an inch or three fourth of an inch until the named criteria are attained (4) The *hemostatic element*—leave the wound dry because blood serum and macerated



tissue become an autogenous culture medium, virtually a bouillon to promote growth of organisms. (5) *The sterilizing element*—place on and in the wound a sulfonamide, preferably sulfanilamide. In amount this should coat the entire area liberally. Too much rather than too little should be applied. (6) *The suture element*—if the wound is of the lacerated type, abandon any idea of suturing it; instead place the sutures but do not tie them until the third day if all goes well. This is primosecondary suture and it is by far the best form of treatment for ordinary wounds from any source. In wounds that are very deep or very ragged, the area is left wide open and no suturing of any type is used. (7) *The dressing element*—heavy gauze and cotton applications are used because rest and immobilization are important factors. If joints are contiguous, they should be splinted to provide additional immobilization; then the parts should be elevated and tilted if possible to promote drainage. (8) *The after-care element*—a sulfonamide is given by mouth, and our practice at Pearl Harbor was to give 15 gr. of sulfanilamide each four hours for three days postoperatively. No redressings are done until the third day unless there are contraindications.

All redressings should be done with great care to avoid re-infection, hence a sterile clamp and thumb forceps should be used so that no soiled fingers or hands will contact the area involved nor touch any of the dressings. This is a blacksmith's technic because he uses tongs to touch his operative field and to handle his red hot material.

For the ordinary wound—the abrasions and scratches of the skin—deep variety—the routine is the same as far as the time element, the soap-and-water cleansing element and the powdering of the area with a sulfonamide are concerned. As to suturing this type, we may say that *primary or immediate suture* is permissible in recent superficial wounds that are well cleansed. However, the interrupted sutures should not be too numerous nor tight, and safety is added if a drain is inserted, such as a rubber band or a pipe cleaner. Drains, as a rule, should be removed within forty-eight hours.

However, in this superficial group if there is soil or debris contamination, the practice of primosecondary suture is best. As a matter of fact, the alignment obtained by this procedure is satisfactory enough even from a cosmetic standpoint.

*The Infected Wound.* These are the cases in which the pus-producing organisms or others have already established themselves. The typical signs such as pain, redness, swelling and systemic symptoms exist. Most cases are of the combined *staphylococcus-streptococcus* group. Less frequent are such invaders as *gas gangrene* and *tetanus*.



For the usual case manifesting pus secretion and cellulitis the treatment is

(1) Provide exit for retained secretion by removing sutures if present

(2) Apply wet dressings of 3 per cent sulfanilamide in water. Keep these moist by attaching tubes to a reservoir, and keep them hot by electric bulbs

(3) When localization occurs, incision is indicated only if and when (a) local fluctuation, (b) local induration and (c) local pain exist. Let the incision be long enough and deep enough to provide self gapping. For drainage use gauze only if bleeding is free or the edges have to be separated. Soak this gauze in 3 per cent sulfanilamide in mineral oil. Do not ram gauze into any wound, that is not surgery, it is taxidermy. Do not incise alone for such symptoms as brawny induration, redness, red streaks or adenitis. If we incise for these indications, we may increase and not decrease the process, and what is more, we may produce a blood stream invasion by our effort.

(4) Give a sulfonamide by mouth, 15 gr. every 4 hours for 3 days.

Gas gangrene involvement was treated at our Pearl Harbor formation by liberal debridement, repeated x ray exposure and sulfanilamide in the wound and by mouth. We used serum in only a few of our eleven cases. All our wounded recovered without re amputation, and in every case of this infection, sutures had been used. Tetanus yields usually to serum but we must not forget that debridement and sulfanilamide locally and by mouth are necessary adjuncts.

In any infection, the combating and sustaining power of transfusion dominate the program.

Thus to sum up, we treat war wounds in terms of (1) Time, (2) soap and water cleansing, (3) debridement, (4) primo secondary or no suturing, (5) sulfonamides locally and internally, (6) adequate dressings, (7) careful redressings, (8) blood for shock and infection, (9) no secondary incisions except for localization, (10) debridement, sulfonamides and x ray for gas gangrene, and (11) antiserum for tetanus.

Just a word or two regarding substitutes for the proved by experience sulfonamides. We are beginning to hear of the earth born derivatives called *penicillin* and *gramicidin* and these may prove in the future to be potent weapons in our surgical war. But until these reinforcements arrive, let us rely on the ammunition that continues to render such valiant aid—the *sulfonamides*. We should take every advantage of these weapons that so effectively kill our germ enemies. Let safety first be our guide, and to that end suspect every wound of being hostile until proof to the contrary is demonstrated.



## HEALING OF WOUNDS

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Wound healing is a process which intimately concerns every surgeon but this fundamental subject has received only superficial consideration, for the most part, until very recently when the basic principles have begun to be more widely appreciated. This discussion attempts to epitomize the known facts from various angles, basic and clinical.

### *Biophysics of Wound Healing*

As soon as a wound to tissue is sustained, serum and blood accumulate and coagulate in the wound space and to a lesser degree in the interstices between the surrounding uninjured cells. Into this damaged area, cellular elements of the blood, wandering tissue cells and new capillary loops are attracted. These capillary loops make up granulation tissue which pulls the wound edges together as the fibroblasts mature. This briefly is the entire process of normal healing and it is dependent on certain fundamental phenomena, namely: ameboid movement of cells, mitotic proliferation of cells and maturation of cells engaged in fusion of wound surfaces. Ameboid movement of cells is stimulated by the presence of blood, tissue fluids and a large number of other substances. Inadequacy of oxygen and nutritive substances in the relatively ischemic border of the wound may cause tissue hunger and anoxia followed by cell division and ameboid activity of fibroblasts and endothelial buds. Immediately after tissue injury the lytic phase of wound healing begins and here the dead tissue elements are removed by phagocytes. This also is called the lag phase because reparative processes do not begin until toward the end of the lytic phase. Phagocytosis is followed by an influx of wandering connective tissue cells and then proliferation of the invading fibroblasts begins. Now, two fundamental processes begin to operate. The stereotropic response of growing cells to surfaces causes the growing fibroblasts to elongate along the fibrils of the fibrin network in the coagulum filling the wound space just as epithelial cells show ameboid movement along plane surfaces of granulation tissue and beneath crusts. This stereotropic response thus causes the fibroblasts to grow out and invade the wound space on the trellis of fibrin fibrils. A second factor which operates toward the same end is that of centrifugal force which directs growing cells away from their own kind and so into the plasma mass in the wound space. Endothelial buds also exhibit this phenomenon which may be an electrochemical mechanism; like cells



with like surface charges tending to repel each other. Wounds become firm as the maturing fibroblasts contract and surface epithelialization progresses. The expected time of healing of any wound readily can be computed mathematically using the Carrell DuNouy<sup>1</sup> formula which is calculated on the basis of surface area. These computations also apply to the healing of granulating cavities such as those seen in empyema. I have previously shown this to be the case in some unpublished work quoted by Carlson.<sup>2</sup>

### **Systemic Conditions Influencing Wound Healing**

1 Tissue age whether adolescent normal adult senescent or degenerated influences the rate of wound healing not only because young tissues heal most readily but because old tissues are apt to show vascular changes which retard healing. 2 The state of hydration of the tissues as determined by water electrolyte and protein balance in the blood exerts a profound effect on wound healing and these factors will be discussed separately and in more detail later. 3 Normal nutritional balance is a somewhat vague term which probably covers the aggregate of many of the other factors which influence wound healing. 4 Vitamin balance will be discussed in detail later and will be found to be one of the most fundamental but least known influences on wound healing. 5 The general state of circulation and blood picture influence wound healing as they affect the interchange of cellular and ionizable elements between normal and damaged tissues.

### **Local Factors Influencing Wound Healing**

1 There is a quantitative relationship between the amount of killed or damaged tissue in the wound and the time required for phagocytosis and repair. 2 Vascularity of the tissues involved is of prime importance in wound healing. Avascular tissues must depend on lymph spaces for interchange of nutritive and waste materials and since most authorities deny that lymph flows this interchange depends upon diffusion gradients for exchange of ionizable substances and amoeboid motion for ingress of cells. 3 As a corollary to the preceding statement the local blood supply to the wound must be intact for no matter how vascular the tissue if the blood supply is jeopardized by trauma healing will be retarded in direct ratio. 4 The amount and character of the exudate in the wound space and in the tissues bordering on the wound determine the rate of healing in large measure. 5 The number and nature of the infectious organisms in the wound space and bordering tissues have a profound bearing on wound healing as infection throws an added burden on the reparative



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mechanism. 6. The number and type of foreign bodies which must be encapsulated or extruded from the wound influence the rapidity of wound healing.

### **Relation of Tissue Ph to Wound Healing**

Normal tissues preserve a neutral reaction by means of diffusion between the blood stream and local tissue spaces. Injured tissue accumulates acid metabolites and the break-down of dead tissue also liberates split protein products which are acid in reaction. These factors influence the injured area and cause a shift in Ph toward the acid side. Menkin<sup>3</sup> shows that neutrophilic leucocytes are attracted to slightly acid areas and these cells therefore congregate in the injured area. If acidity exceeds the optimum point, the neutrophilic leucocytes are killed and macrophages are attracted. If the macrophages are able to phagocytose enough dead tissue to decrease the acidity, the inflammatory reaction regresses but on the other hand, if the acidity increases, the macrophages also are killed and suppuration results. As the neutral stage is regained, such cells as the lymphocytes and plasma cells migrate to the site of reaction. From this discussion it seems that chemotaxis is largely responsible for the accumulation of the various cellular elements at the site of inflammatory reaction.

### **Role of Vitamins in Wound Healing**

Vitamin A deficiency causes such clinical manifestations as night blindness, photophobia, dry skin, dry conjunctivae, blepharitis, follicular hyperkeratosis and numerous or severe infections. This latter may be of some importance in wound healing but such terms as "local tissue immunity" and "site of local lowered tissue resistance" usually are employed only to cover ignorance. About 35 to 50% of people show deficiency in Vitamin A by the photometric test; however this test is not generally accepted as accurate. About 12% of individuals show clinical deficiency of Vitamin A as evidenced by one or more of the previously mentioned clinical manifestations.

Of the Vitamin B complex, B1 or thiamin chloride seems to be the only factor of importance in the healing process. B1 seems to be identical with one of the components of the carboxylase enzyme system governing metabolism in nerve tissue. Therefore Vitamin B1 is of importance in the healing of injuries to nerve tissue.

Vitamin C (ascorbic or cevitamic acid) is the most essential vitamin in the healing process because intercellular substance in general and in the capillary bed in particular as well as the collagen of all fibrous tissue



requires cevitamic acid for its production and maintenance. Lack of Vitamin C causes hemorrhage into the wound space with a lag in healing and a tendency to wound disruption. Vitamin C deficiency in experimental animals has been shown to delay return of tensile strength in wounds. About 40% of indigent clinic patients are deficient in Vitamin C and all patients over seventy years of age show a relative deficiency. Patients placed on a strict ulcer diet become deficient in Vitamin C within four days. These figures are arrived at by using the skin test or the capillary fragility test. Many superficial studies of wound dehiscence have been published and various factors have been blamed but it seems reasonable and probable that Vitamin C deficiency is the most universal and important factor. Vitamin C deficiency has many other interesting implications as has been emphasized recently by Levine<sup>4</sup> who states that German soldiers receive 100 mgm of crystalline Vitamin C daily.

Vitamin D is irradiated ergosterol which is related to cholesterol, one of the group of sterols which are of extreme importance in basic cell physiology because the sterols are responsible for the selective permeability of cell membranes. The presence of these sterols in the surface film enables the cell membrane to change its colloidal state from a water in oil to an oil in water emulsoid and therefore both oily and aqueous substances may be taken into the cell, selectively.

Vitamin K, a water soluble naphthohydroquinone is responsible for maintaining the level of blood prothrombin. K is absorbed from the gastrointestinal tract only in the presence of bile so that in cases of biliary obstruction, K is not absorbed, the prothrombin level drops and the patient tends to bleed. Vitamin K deficiency is of importance in wound healing only in patients having biliary obstruction.

The story of vitamins is not yet told but this seems to sum up our present knowledge of vitamins as they relate to wound healing.

### Relation of State of Hydration to Wound Healing

Water is necessary to carry nutritive elements and waste products in solution and since these solutions must be isotonic with blood, relatively large quantities of fluid are essential. The many other implications of this important subject have been covered by the papers of Collier and Maddock.<sup>5</sup> Suffice it to say here that either too much or too little fluid retards wound healing. The state of hydration of the surgical patient may be gauged by 1 The urinary output 2 Specific gravity of the blood as measured by the falling drop method<sup>6</sup> 3 The McClure Aldrich salt edema test<sup>7</sup> The surgical patient must have a daily urinary output



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of at least 600 cc and preferably 1000 cc. The falling drop test measures the concentration of the blood and by the use of a simple chart, blood protein levels may be quickly read off. The McClure-Aldrich salt edema test depends on absorption of skin wheals of normal saline solution and the rapidity of absorption is an index of the tissue hunger for fluid and salt.

### **Relation of Electrolyte Balance to Wound Healing**

Sodium chloride is the most important electrolyte and is almost entirely responsible for the osmotic pressure of intercellular fluid. Accumulation of salt in the tissues attracts fluid, edema develops and edematous tissues do not heal properly because of altered pressure relationships and insufficient ingress and egress of materials. Decreased concentration of salt in the tissues causes a loss of fluid into the vessels with consequent tissue dehydration. Adequate fluid balance therefore depends on salt balance and both are very important in wound healing.

### **Relation of Level of Proteinemia to Wound Healing**

Protein is the most important colloid element of blood and as the quantitative level of blood protein is decreased, the osmotic pressure and diffusion gradient are so altered that fluid tends to leave the vessels and accumulate in the tissue spaces. Blood protein levels of lower than 5 mgm % result in this type of edema. Deficiency of protein as well as edema, retard wound healing. Ravdin<sup>8</sup> has shown that abdominal wound disruption developed in over 70% of dogs operated upon in the presence of hypoproteinemia. There was little or no evidence of fibroplasia in these cases up to two weeks after operation. On the other hand, a high protein diet speeds up wound healing and almost eliminates the lag phase.

### **Relation of Metabolic Rate to Wound Healing**

Theoretically, an increase in basal metabolic rate should speed the healing process but such does not seem to be the case. Goiter incisions in patients with very high metabolic rates do not heal any more readily than other types of incisions about the neck. Routine administration of thyroid extract post-operatively to speed wound healing and increase the circulatory rate to prevent thrombophlebitis has been advocated but has not proven to be of value.

### **Relation of Local Blood Flow to Wound Healing**

Local blood flow brings in most of the cellular elements which are so



important in wound healing brings in nutritive elements and carries off metabolites. In addition there is a very important mechanical factor to be considered. If a large vein is damaged it should be ligated because the thin wall precludes suture and since veins usually are multiple sufficient venous channels will remain. If a large artery is damaged it should be sutured if feasible but if this is impossible a very different physiological problem arises. Blalock has shown that if a large artery is ligated its accompanying vein also should be ligated. This procedure has the effect of causing blood to remain longer in the involved area and thus the injured tissues have more time to make use of it. If the artery alone is ligated the venous channels of return overbalance the arterial supply and the area is drained of blood. Ischemic gangrene may be the result. This is a very difficult point to make and while many surgeons advocate and teach it few have the courage of their convictions. The rationale is clear and I have seen it work in practice.

### **Effects of Temperature on Wound Healing**

The application of heat to most potentially infected wounds by the use of hot packs, hot water bottles or light cradles is almost universal but may be very dangerous. There may be three serious disadvantages to the use of heat on wounds. 1 Heat may speed up local tissue metabolism to the point where the damaged vessels cannot adequately supply the increased demand for fuel and gangrene results. This is more frequent than is realized in such cases as diabetic infections which progress to gangrene. 2 Heat cannot be carried away because of damaged vessels so that a cumulative effect is present and causes increased tissue damage. 3 Heat augments capillary filtration and so increases local edema which may or may not be beneficial as will be discussed later. It is a safe rule never to use external heat of more than 100 degrees and a thermometer always should be hung in the light cradle. Refrigeration in the presence of vascular damage probably is more rational than the use of heat. Refrigeration decreases metabolic needs so that a damaged circulation may be adequate. Fay has applied this principle to the treatment of carcinoma because malignant tissue has a higher metabolic rate than normal tissue and refrigeration may cause death of tumor tissue before normal tissue is affected.

### **Role of Pressure and Tissue Tension in Wound Healing**

I previously have shown<sup>9</sup> that in a hollow viscus distention of the lumen or increase in the tissue tension will cut off blood flow sufficiently to cause inflammatory changes within the walls and this will progress to



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gangrene and perforation even in the complete absence of bacterial infection. Wound healing in other tissues is slowed by increased pressure or tissue tension because of reduction in blood flow or hindrance to physico-chemical processes. Brooks<sup>10</sup> showed that the period of viability of tissues rendered completely anemic by pressure is remarkably constant at 18 hours. The time element seems to be much more important than the degree of pressure because very low pressures may cause gangrene if applied constantly over a long period of time. Edema or external appliances may exert sufficient pressure to cause tissue damage and mild degrees of damage heal by fibrosis which in such cases as Volkmann's contracture, may lead to serious dysfunction.

### **Immobilization and Elevation in the Treatment of Wounds**

Immobilization is a well established principle in the treatment of fractures but its benefits in soft tissue wounds are not so generally appreciated. Complete immobilization in soft tissue injuries not only facilitates healing but relieves pain, prevents deforming contractures and facilitates nursing care. Immobilization for soft tissue wounds was used extensively in the late Spanish war and has been exhaustively discussed by Trueta and others.

Elevation of the injured part makes use of the force of gravity to aid in return of blood and lymph from the site of injury and is an extremely important mechanical principle. The fundamental question as to whether the inflammatory reaction to healing and infection is the result of bacterial action or is a defense mechanism on the part of the host, has never been satisfactorily answered. If the former, then treatment should combat the reaction and if the latter, therapeutic measures should augment the reaction. Edema fluid is said to contain anti-bodies and swelling may occlude tissue spaces and inhibit bacterial spread. On the other hand, edema increases pain, decreases circulation, slows healing and may provide a fluid medium through which bacteria disseminate. Elevation of the affected part definitely reduces inflammatory edema and makes the patient more comfortable. Healing is facilitated but there are two dangers connected with the use of elevation. 1. Elevation of the lower extremity puts an extra load on the vascular system because blood does not flow up hill without work. Particularly in older patients, the angle of circulatory efficiency must be watched closely. The toes of elevated extremities should be checked repeatedly for drop in temperature and the vessels must be palpated for adequate circulation. I have seen a number of cases of gangrene develop from excessive elevation of the leg in young persons. 2. Elevation causes pus to settle by gravity and



travel along fascial planes toward the trunk. I have seen several huge gravitational abscesses develop under casts applied with the leg in elevation where the abscess was some distance proximal to the original infection. The papers of Wingensteen<sup>11</sup> discuss the factors of immobilization and elevation in the treatment of wounds in considerable detail.

### Primary vs Delayed Closure of Wounds

The decision as to whether primary or delayed closure of a wound is to be employed depends on the time that has elapsed since the injury and also on the degree of obvious contamination. Primary closure in a clean wound is indicated up to 8 hours after injury but recently I have seen wounds of much longer duration involving tendon suture primarily closed with good results by implanting sulfanilamide powder at operation. Ordinarily however dirty wounds or clean wounds seen after 8 hours are treated by delayed closure. If the wound meets the criteria for primary closure it should be flushed with large quantities of saline solution or washed repeatedly with soap and water. Bad habits are difficult to eradicate so that the instillation of so called antiseptic solutions into wounds still is practiced widely. Closure should be accurate but without tension. Silk sutures may be used in clean cases but catgut is safer because of the disagreeable sequellae if silk is used in the presence of infection. Catgut has a number of disadvantages among which may be mentioned the fact that it is a foreign protein and occasions a certain amount of inflammatory reaction during its ultimate liquefaction and absorption. Certain patients absorb catgut very rapidly and there is some question of allergy in these cases. In wounds which are doubtfully clean it is possible to place adhesive tape close along the wound edges and then to suture the adhesive instead of the tissue. This procedure makes it a simple matter to open the incision if infection develops. If the wound does not meet the requirements for primary closure it should be treated in one of the ways to be discussed later and then when a smear from the granulating surface shows a bacterial count of less than 10 organisms per high power field secondary closure may be done or the wound may be covered by a skin graft.

### Debridement of Wounds

Contused and multiple lacerated wounds require careful excision of all obviously devitalized tissue because of the danger of infection particularly by the anaerobic organisms of tetanus and gas gangrene if dead tissue remains to use up oxygen and act as a culture medium. A study of ballistics shows that for various sizes and velocities of projectiles



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there are definite areas of tissue on all sides of the injury which subsequently will die as a result of the concussion. Therefore, it is important for the surgeon to know what type of projectile caused the injury in order to determine how much tissue to remove. Poor judgment in this matter may seriously affect subsequent healing.

### **Antiseptics in Infection and Wound Healing**

Many kinds of saprophytic bacteria and higher organisms live on the normal human skin, the number and kind depending on the environment and the degree of personal hygiene of the individual. A clean skin usually shows 12 staphylococci or diphtheroids per square centimeter. Other common organisms in addition to fungi are spore formers, the colon group, and bacillus *Proteus*. This indicates that all wounds are at least potentially contaminated but simple flushing of wounds with saline solution or soap and water usually suffices to remove these non-pathogenic organisms. However, from time immemorial, men have searched for the magic colored solution which will kill bacteria but not harm tissues. Notwithstanding the expensive and varicolored solutions on the market today, such a desideratum has not yet been attained. The practice of pouring these solutions into defenseless wounds simply increases the tissue burden and should be discontinued. Novak<sup>12</sup> showed that all common alcoholic antiseptics kill 96 to 99% of skin organisms but 50% alcohol plus 10% acetone alone kills 97%. It therefore seems irrational to pay \$10 a gallon for certain commercial solutions. Novak made up a solution of .5% cresol and .07% bichloride of mercury in 50% alcohol and 10% acetone solution. This solution kills 100% of diphtheroids, 99.6% of staphylococci, costs but 60 cents a gallon and has been successfully used clinically for at least three years at the University of Minnesota General Hospital. Novak solution has been used for skin preparation at the Station Hospital, Ft. Leonard Wood, Mo., since the hospital opened on May 3, 1941, with an extremely low incidence of wound infections.

### **Treatment of Infected Wounds**

The fact that such a large number of agents have been recommended for the treatment of infected wounds indicates that the ideal method has not been discovered. However, it is well to bear in mind the outstanding points in the use of these various substances.

*Dakinization.* Dakin's solution is an aqueous buffered solution of sodium hypochlorite which liberates chlorine. Chlorine has the effect of liquefying fibrin, dissolving dead tissue, killing bacteria and therefore is



beneficial in any infected wound. The solution has the disadvantages of rapid deterioration, short action, objectionable odor and requires an elaborate system of bottles and tubes for proper use. Dakin's solution dissolves the cornified layers of normal skin and therefore the area around the wound must be protected by vaseline gauze. The solution will sterilize a wound in 48 hours if correctly used and will transform pus into a transparent, mucinous substance with only a slight chlorine odor. Azochloramide is a more stable preparation which liberates chlorine over a longer period and consequently is less irritating to normal tissue. Dichloramine T is an oily preparation which disintegrates still more slowly. Dakin's solution was extensively used in the last World War but it is predicted that it will be little used in the coming war.

*Maggot Treatment* Maggots were first introduced in the treatment of chronic osteomyelitis because it was observed that infested cases were found to be the cleanest. The application later was broadened to include all infected necrotic wounds. There are several ideas as to why the larvae are effective. 1 It has been suggested that the larvae actually eat the dead tissue and purulent exudate, thus mechanically cleaning up the wound. 2 It has been thought that larval excretions are responsible for the healing effect. 3 Dead larvae are thought to liberate a substance which is bacteriacidal. The use of live maggots is objectionable to patients because of the crawling of the maggots and from the esthetic viewpoint. Furthermore the treatment is difficult to carry out because it is hard to obtain sterile maggots as needed. The problem has been approached by an effort to isolate the effective principle and by the application of macerated larvae in saline solution or ointment form.<sup>13</sup> Experimental evidence shows that these extracts and ointments definitely promote healing and at present, it does not seem necessary to use live maggots.

*Cod Liver Oil* Cod liver oil is very valuable in the treatment of any infected wound and in prophylaxis in any open wound. The oil discourages bacterial growth and has a marked stimulating effect on granulation tissue. There may be some truth in the claim that Vitamin D is the effective agent because it is known that oxidized odorous oil is more efficacious than the highly purified product. Also, irradiation of other oils increases their healing properties. Cod liver oil may be used to fill cavities and soak dressings or may be used as a 30 to 50% ointment in vaseline. Cod liver oil is of great usefulness in the treatment of infected wounds, empyema, chronic osteomyelitis, suppurative arthritis, burns, arteriosclerotic and diabetic gangrene.

*Oxidizing Agents* Certain bacteria grow best in an atmosphere of



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lowered oxygen tension and grow well in symbiosis because one organism uses up oxygen thus making an anaerobic medium for the other. A microaerophilic streptococcus is such an organism and cause a gangrenous spreading infection. One means of treatment is debridement followed by the application of a substance which breaks down to liberate oxygen. Meleny has popularized the use of zinc peroxide in such cases. This agent comes in powder form which is sterilized and then made into a thin paste with sterile water. The wound then is filled with paste-saturated sponges and a large air-tight dressing is applied to inhibit evaporation and to prevent the rapid escape of oxygen.

*Chlorophyll.* Various vegetable substances recently have been advocated for use in treatment of infected wounds. Of these, chlorophyll<sup>14</sup> has received the widest trial. Chlorophyll inhibits bacterial growth apparently by preventing bacterial enzymic digestion of cell membranes. It is used in aqueous solution or in an oily base for suppositories or ointments. It may be given intravenously, by mouth or may be used as an irrigating fluid. Chlorophyll cleans up the wound and stimulates granulation tissue. It has had extensive clinical trial in such cases as wound infections, empyema, fistulae, deep abscesses, acute infections of the nose, throat and ear, male and female urinary tract infections. This substance should be cheap, easy to prepare and almost universally present. It is interesting to speculate as to what role the vitamins in green vegetation may play in the healing effect of aqueous extracts.

*Barberry.* Folk lore remedies which have stood the test of time deserve scientific investigation in order to isolate whatever specific principle may be present. One example of such work is the recent investigation of barberry by Dick.<sup>15</sup> Barberry has been widely used for centuries by aborigines as an infusion to cure surface infections and gonorrhea. Experimental work shows the effective agent to be berberine which in 1% solution kills erysipelas streptococci in 8 hours. Clinically, berberine has been successfully used in wound infections, decubitus and varicose ulcers and mouth infections. It is dangerous when administered intravenously.

*Pectin.* Another folk remedy of proven worth is the apple diet for infantile diarrhea. The effective agent now is known to be pectin which is found to be bacteriostatic in aqueous solution and stimulating to granulation tissue. Tompkins<sup>16</sup> and others have shown its worth in the treatment of various wound infections.

*Silicon.* The use of silicon in the treatment of wounds has a very interesting background. Mountain dwellers of Virginia have a tradition that eating sand will cause peptic ulcers to cease bleeding and this led to an investigation of silicon. It is known that silicon in the lung causes



intense fibrosis of the pulmonary tissue and Gardner has shown that this is in inverse ratio to the size of the particles of silicon. It seems established then that silicon promotes fibrosis and the idea that silicon might cause wounds to fibrose was given a clinical trial with striking results. Silicon was ground to the finest powder and used in all types of wounds and ulcers with prompt healing. Silicon was given by mouth for bleeding ulcers and by cystoscope for bleeding tumors with equally good results. I saw these cases demonstrated in the Department of Surgery at the University of Cincinnati in 1934 and was deeply impressed but to my knowledge the work never was published. They were able to show elevation in the level of blood silicon by oral administration with favorable results in wound healing.

*Specific Sera and Antitoxins* Gas gangrene caused by *Cl. Welchii* is a frequent complication of war wounds because these anaerobic organisms are almost universally found in dirt. This complication is much dreaded because the gas generated by the organisms rapidly spreads along tissue planes and produces pressure necrosis of tissue. Manson has shown a 35% incidence of *Cl. Welchii* in indolent leg ulcers and this has given undue alarm to many surgeons doing amputations in cases of diabetic or arteriosclerotic gangrene. In a published series Kennedy and I<sup>17</sup> have shown that 38% of milk cultures made at operation and at the site of amputation were positive for gas forming organisms but in no case was anti gas serum given and in no case did gas gangrene develop. This illustrates our point that most of these gas formers are relatively non pathogenic and if amputation is done according to the criteria we laid down favorable results will follow in a higher than usual percent of cases. Formerly gas gangrene was treated by massive doses of antitoxin but its value is open to question and the danger of foreign protein sensitization is great. Injection of oxygen into the tissues has been used with some success but the most beneficial treatment seems to be with the x ray or the local use of sulfanilamide. Tetanus is caused by *Bacillus tetani* also a dirt organism and is the cause of a high mortality rate. There is nothing new in the treatment of this disease but it is suggested that zinc peroxide x ray therapy and sulfonamide derivatives give enough promise to warrant investigative work. One answer to the problem may lie in the universal toxoid immunization to tetanus now employed by the Army but some alarming anaphylactic reactions are being reported.

*X ray Therapy* Since the striking work of Kelley in the treatment of gas gangrene peritonitis and other severe infections by x ray therapy it has been suggested that it be used in the early treatment of war



wounds. Keating and Davis<sup>18</sup> suggest that portable x-ray therapy units be placed with mobile Surgical Hospitals which already have power plants mounted on trucks. All dirty wounds would be treated within four hours after injury. This procedure is not to be recommended for three reasons; 1. Slight overdosage of x-ray therapy delays wound healing and may cause other well-known and more serious consequences. X-ray therapy given in all Surgical Hospitals would require many more trained radiologists than are available. 2. Not only is there danger of overdosage at one sitting but it is quite likely that in the rush of battle evacuation, records might not be completed so that patients might be treated twice. Such mistakes are not entirely beyond the bounds of possibility. 3. Local implantation of sulfanilamide is so astonishingly successful in combating wound infection that it should not be discarded in favor of x-ray therapy and most authorities state that the two modes of treatment should not be employed in the same case.

*Sulfonamide Drugs.* Sulfanilamide and its derivatives seem to act as bacteriostatics by virtue of their power to prevent bacterial cells from utilizing oxygen. Sulfapyridine was introduced to combat staphylococci but it is relatively insoluble, gives a higher incidence of gastro-intestinal upsets and now is little used. Sulfathiazole is well tolerated by mouth, in solution in cod liver oil or in ointment form. Excellent results have been reported from its use in carbuncles, operative wound infections, decubitus ulcers, corneal ulcers, chronic osteomyelitis, empyema and subcutaneous abscesses.<sup>19</sup> However, sulfathiazole is less soluble than the original sulfanilamide which is preferred for local implantation.

Local implantation of sulfanilamide crystals was first used in compound fractures by Jensen<sup>20</sup> who reduced the previous incidence of severe infections from 25% to nearly zero. Implantation gives a local concentration up to 800 mgm % as compared with 10 mgm % which is attained with difficulty by oral administration of the drug. This concentration is so great that all organisms are affected, regardless of whether or not sulfanilamide is specific for them. Saturated solutions of the drug may be used to irrigate infected cavities with excellent results. Local implantation of sulfanilamide around complicated gastro-intestinal anastomoses<sup>21</sup> has greatly reduced the mortality and its use free in the peritoneal cavity in cases of peritonitis has been beneficial.

It is to be remembered, however, that sulfanilamide is absorbed with great rapidity from the peritoneal cavity, its maximum blood level often being reached in 15 minutes after implantation. For this reason, the liver may be fatally damaged unless care is taken to use no more than 5 grams of the drug. I have seen three patients die of toxic hepatitis following



the intraperitoneal introduction of 10 grams of the drug. It is suggested that every soldier be furnished with 5 gram ampules of sulfanilamide with instructions to break one and pour the contents into a wound whatever the site as soon as incurred. The question of having the soldier begin oral administration of the drug or one of its derivatives also immediately after injury should receive earnest consideration.

## Summary

Biophysical mechanical chemical and bacterial factors are briefly considered as they relate to wound healing. The use of various and diverse substances in the treatment of infected wounds is discussed and numerous points are raised with the hope that additional investigative work will be stimulated.

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## THE TREATMENT OF WAR BURNS

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Burns and scalds form probably the earliest wounds treated by mankind. They have been known in ancient methods of warfare, and have formed quite a high casualty list in modern campaigns. Yet, never until the present conflict have burns and scalds been so numerous. There are many reasons for this great increase. First, the present war as the Germans are waging it, is a total war, and the bombing attacks are indiscriminate, and therefore the civil population, often women and children, may suffer the most. Second, the greatly extended use of mechanical transport with its oil fuel has been responsible for an increase in burns and scalds among the general public. Third, on the Navy, Army and Air Force, with their greatly extended use of petrol, and the fact that dive bombing on the warship and tank is a common procedure, the casualties due to burns have multiplied.

In the war of 1914-18 a large proportion of burns in the fighting services were caused by cordite, largely due to backflash down the ammunition shafts of fighting ships. This cause has been eliminated for all practical purposes in this war, owing to the fact that with the present mechanical arrangements, backflash is now impossible, and so cordite burns are rare. The common causes of burns and scalds as seen in the present war are petrol, burning oil, phosphorus pipes, electric burns due to severed cables or short circuits. Quite a number of bad burns have occurred among the fire fighting personnel, due to the intensive heat of burning buildings ignited by incendiary bombs. In a large collection of cases burns and scalds are the only injury present, yet on the other hand, there are always a number of cases both among the civilian population and in the fighting services, where the burns are complicated by open wounds or fractures. However in quite a proportion of burns in the Royal Navy the commonest complication is "blast lung" a condition which varies from a triviality to a most serious and fatal manifestation. Another complication which is not too well-known is fat embolism; this is found to be present in 40 per cent of burn cases which have proved fatal.

In times of peace the treatment of burns is quite standardized and straightforward, and most of the cases receive hospital treatment within one hour of the accident; therefore the results should be better and the mortality lower than those treated under war conditions. Again burns



and scalds in peacetime are frequently the only lesion to be treated while in modern warfare there are often associated injuries. In this war there is the added complication of blast injuries both in civilian and service burns, because so many are caused by bomb flash.

During the last fifteen years much research has taken place concerning burns. This was initiated by Davidson, of Detroit, in 1925, who introduced tannic acid in the treatment of burns. The coagulation of the burnt area by tannic acid reduced the mortality of burns enormously, and prior to the war was universally used for all cases with great success. However, under war conditions burns do not always get immediate attention and sepsis is a very common complication.

### Classification of Burns

Dupuytren described six different degrees of burns as follows.

The *first* degree consists merely in a scorch or superficial congestion of the skin without destruction of tissue, the part may for a time remain red, painful and prone to ulceration.

In the *second* degree the cuticle is raised from the cutis, and a bleb or blister results. When this bursts, and the cuticle is removed, the cutis vera, red and painful, is exposed below.

In the *third* degree the cuticle is destroyed, as is also part of the cutis vera, but the tips of the interpapillary processes, including the exquisitely sensitive nerve terminals, are laid bare and left intact, consequently this is the most painful form of burn. The deeper structures of the skin, viz., the sweat and sebaceous glands, and the hair follicles, are not destroyed, so that although the surface during the healing process becomes covered with granulations since there are so many surviving epithelial elements from which it can grow, the integument is very rapidly replaced. The cuticle is able to form, not only from the edge, as must occur whenever the whole of the cutaneous envelope is destroyed, but from innumerable foci scattered over the wound surface. The resulting scar, though often white and visible, undergoes no contraction, it is supple and elastic from containing all the elements of the true skin. In the *fourth* degree the whole thickness of the integument is destroyed as well as part of the subcutaneous tissues. In the *fifth* the muscles are also involved whilst in the *sixth* the whole limb or other affected part is completely charred and disorganized.

While this classification has been in use during the last one hundred years, yet it is a little too cumbersome and from a practical standpoint it is better to consider only three degrees: the first being an erythema, the second causing destruction of the epidermis with or without vesica



## *The Treatment of War Burns*

tion, the third degree causing destruction of the whole skin and possibly some or all of the deeper tissues.

The treatment of burns is in reality a threefold problem. First, the saving of life; second, the local treatment of the burned areas; and third, the preservation of function of the parts involved.

In every case of burns there is always some shock present and this must be dealt with before any form of local treatment is attempted.

### *Treatment of Shock*

This consists in the early administration of morphia in adequate doses. Men require  $\frac{1}{2}$  gr. and this should be repeated if pain is not

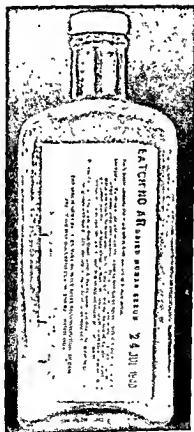


FIG. 1.—Dried human serum. Each bottle contains the dried solids from 200 c.c. of human serum. *Solution:* To reconstitute add under sterile precautions nonpyrogenic sterile distilled water; i.e., B.P. distilled water autoclaved immediately after distillation. The levels for the different concentrations to which the bottle should be filled are indicated on the side of the label. Solution at four times normal concentration takes about sixty minutes, at normal concentration about ten minutes. With concentrated solutions, the rate of transfusion should not exceed 50 c.c. in ten minutes. *Blood Group:* The serum is from Blood Group A, but experience has shown that it can be given to all blood groups with safety. (Preliminary typing is therefore not required.) The serum must be given very shortly after reconstitution, in case infection has occurred during the reconstitution. The higher level on the side of the label indicates twice normal concentration.



relieved Warmth and rest are just as essential as the relief of pain and can be easily given under most conditions Shock cradles and electric blankets are most useful in warming up shocked patients Fluids by mouth should be encouraged but in extensive burns this is not sufficient in itself to make up for the plasma lost from the surface of the burnt area and for that which accumulates in the tissues By animal experiment it has been shown that this plasma loss is greatest in third degree burns, and amounts to over 70 per cent of the total blood volume in cases in which one sixth of the body surface has been burnt

The amount of plasma lost from the surface of the burnt area is quite small in comparison with the amount that accumulates in the tissues This fluid imbalance is a shift of fluid rather than an external loss The result of this fluid shift is a definite fall in blood pressure Tissue fluids deficient in protein pass into the blood vessels in an attempt to maintain the volume of plasma in circulation, this however, results in a lowering of the concentration of protein in the plasma There is also a high urinary output of nitrogen due to the destruction of protein The plasma loss causes a very definite hemoconcentration and it has been quite common to find that the hemoglobin percentage is 120 to 140 in extensive burns in the Royal Navy The introduction of citrated plasma and reconstituted serum has reduced the mortality of war burns very considerably Dried serum can be carried on any warship and it can easily and readily be converted into fluid by the addition of the requisite amount of distilled water The reconstituted serum may be of normal concentration, twice normal concentration or four times normal concentration (Fig 1)

Any patient suffering from burns must have his hemoglobin estimated and if the percentage is above 100 then plasma should be given Witts recommends the giving of plasma to any patient in whom the hemoglobin is 10 per cent above the probable previous value, if this was 100, the plasma loss can be calculated from the formula

$$\frac{Hb}{100} = \frac{5}{5-x}$$

where x is the plasma lost in liters

Plasma of the calculated amount is given quickly and more is given later by slow continuous drips to make good the loss by exudation

Using the above formula Black has worked out the estimation of plasma volume reduction, this has proved of real value to those who have had to treat a large number of serious burn cases

For those cases in which shock is severe intravenous adrenal cortical hormone (cortin) 2 c c should be given repeatedly, and oxygen admin



## *The Treatment of War Burns*

istered by a Boothby mask enables the patient to obtain this in the alveolar air. In cases which are complicated by "blast lung" this form of administering oxygen is most advantageous. In the Navy, where Boothby masks have been in use for all badly shocked burn cases, their value has been inestimable.

**TABLE I**

<i>Hemoglobin % Haldane</i>	<i>Blood Volume (Liters)</i>	<i>Plasma Volume (Liters)</i>	<i>Estimated Deficit in Plasma Volume (c.c.)</i>
100	5.0	3.0	—
105	4.75	2.75	250
110	4.55	2.55	450
115	4.35	2.35	650
120	4.15	2.15	850
125	4.0	2.0	1,000
130	3.85	1.85	1,150
135	3.7	1.7	1,300
140	3.55	1.55	1,450
145	3.45	1.45	1,550
150	3.35	1.35	1,650

*First-Aid Treatment.*—Not until antishock measures have been instituted should any local treatment be attempted. Preliminary cleansing is often impossible as a first-aid measure on board ship during action, or the inside of a tank or aircraft, therefore the use of one of the medicated jellies which are soothing in their application is indispensable. Gentian violet and merthiolate, amertan jelly, tannafax or tannax, all have their advocates, but my preference is the gentian violet preparation. The jelly should be liberally applied on two or three layers of gauze which are then placed over the burnt area and retained by a few turns of a bandage. This first-aid dressing can be left in situ until the patient reaches hospital, unless any areas are seen which have become moist and then they should be retanned with the jelly. Burns of the face, although the gentian violet preparation answers quite well, are probably better treated with cod-liver oil, which is not only an antiseptic but has a high vitamin content. If the eyes are burnt, drops of castor oil containing 1 per cent cocaine should be instilled.

In those cases in which associated injuries are present, such as a wound or a fracture, the gentian violet jelly should be applied to the wound as well as to the burn. If the extremities are involved and compound fractures are present, the limb should be put up in plaster of Paris after the wound and burnt areas have been liberally dressed with the gentian violet jelly.



*Hospital Treatment*—Some cases of burns will arrive in hospital after first aid treatment has been carried out while others will be admitted without any treatment having been given. Some Naval cases have arrived on board hospital ships having spent some time in the sea after having been burnt and have suffered little from shock or pain and after local treatment to the burnt areas have made excellent recoveries. The experience gained from a number of such cases has convinced many medical officers of the great value of saline dressings especially in the treatment of burns of the face and hands but it is essential that the saline dressings are kept moist.

The local treatment of war burns demands the strictest aseptic precautions or sepsis will occur. The surgeon should wear a sterile gown mask and gloves while dressing and inspecting burns. If possible burn cases should be treated in a separate ward and if circumstances permit in separate cubicles divided from each other by glass or mica partitions. This is the ideal method of treating war burns as the likelihood of mixed or cross infection is reduced to the absolute minimum. From an experience of well over 1 000 cases of war burns I am convinced that infection is the commonest cause of the toxemia in burns and that the commonest organism is the hemolytic streptococcus. This organism has been repeatedly grown from blister fluid in the burnt areas in cases which arrive in hospital some hours after the injury. These observations fully confirm the work of Aldrich in 1933 and it is for these reasons that the triple dye method of treatment is given priority in the many methods of treatment of war burns.

## Triple-Dye Method

The patient should be anesthetized with gas and oxygen and all loose and blistered skin should be cut away and the wound area swabbed with warm saline solution. The burnt area is then dried with an electric hair drier and an aqueous solution of triple dye (2 per cent gentian violet 1 per cent brilliant green 0.1 per cent neutral acriflavine) is sprayed on the surface (Fig. 2).

This is then dried and a second application applied which in turn is dried (Fig. 3). Usually two applications are sufficient to produce a nice thin supple tan which is quite adherent everywhere and no sepsis appears around the edges of the tan. In those cases in which sepsis is evident owing to inefficient cleansing and insufficient tanning an anesthetic should be given and the area retanned. It is not always necessary to remove the pre-existing tan.

The dyed burnt areas are not covered with any dressings but the



## *The Treatment of W n Burns*

patient with the exception of the head is shrouded with a hot air cradle. Each day the tan is inspected and any moist areas receive another application of the triple dye. Usually by the end of ten days the tan be

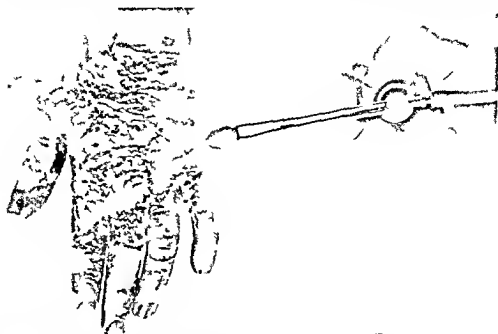


FIG 2—Application of triple dye by means of a spray

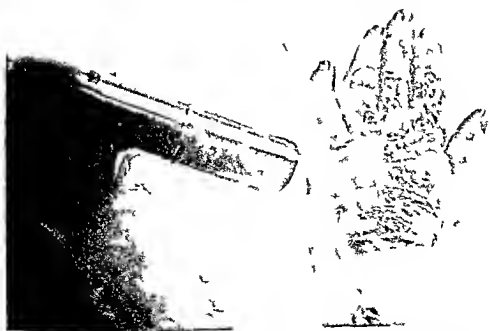


FIG 3—Method of drying the triple dye solution by means of an electric hair dryer



comes quite loose and falls off leaving a healed wound (Figs 4 and 5). If the burn has been extensive and of the third degree, healing will not have taken place but a large granulating area will be exposed after the tan is removed. This area should be treated with a saline dressing for a day and then skin grafted. *There are still too many cases of burns which are allowed to heal by granulation with its subsequent keloidal and fibrous tissue formation.* On the backs of the hands and fingers in



FIG 4—Burn of face due to bomb flash a typical 'blast' injury. This patient suffered from blast lung as well. Photograph taken five hours after injury.

third degree burns early skin grafting makes all the difference between success and failure. The question of the value of sulfanilamide in the treatment of burns is somewhat of a vexed one. I consider that it should be given by mouth for three days only and never used as a powder and dusted over the burnt area. While the sulfanilamide is being administered the patient often vomits and cannot take the increased protein diet which is so essential to his recovery. It must also be remembered





FIG 5—Bomb flash burn of face ten days after injury. Treated with triple dye  
Same case as shown in Fig 4

that fully two thirds of the body sulfur must be replaced. The best method of sulfur replacement is by a liberal diet of eggs and these can not be taken during the sulfanilamide treatment.

#### **Tannic Acid Treatment**

This treatment should not be given until shock has been combated. The actual cleansing of the burnt area is identical with that used before the triple dye is applied. After cleansing with saline solution the area is dried and 1 or 2 per cent gentian violet is applied by swabs and dried by a current of hot air from an electric dryer. A solution of 5 per cent tannic acid is then applied followed by a 10 per cent solution of silver nitrate (Fig 6). A firm hard tin is quickly produced by this method and it is suitable for burns of the trunk but should never be used on the hands or face owing to the bad results that ensue (Fig 7). Numerous cases which have occurred in the present war have produced ample evidence that under the unyielding tannic acid coagulum applied to the hand and fingers an edema develops to a degree which seriously embarrasses the circulation in the fingers with the production of crippling deformities (Figs 8 and 9). This is the result of the treatment and not of the burn.

After the application of the tannic acid the whole affected area should be kept at rest and the limbs should be suspended or splinted. The



patient is nursed in a tented bed containing heating elements and great care should be taken to maintain a dry, unbroken surface

As a rule minor degrees of sepsis can be controlled by gentian violet sprayed on the affected areas after removal of the overlying crust, but if the entire surface becomes infected the tan must be removed by soaking with saline solution or in a saline bath. Retanning should never be undertaken. In third degree burns of large area skin grafting must be performed if scarring is to be prevented.

In the Royal Navy and in the Royal Air Force a large proportion of burns are limited to the hands and face as the clothing protects the rest of the body. It is very essential that full functional results should be obtained without scarring otherwise a considerable proportion of valuable personnel would be invalidated from these Services.

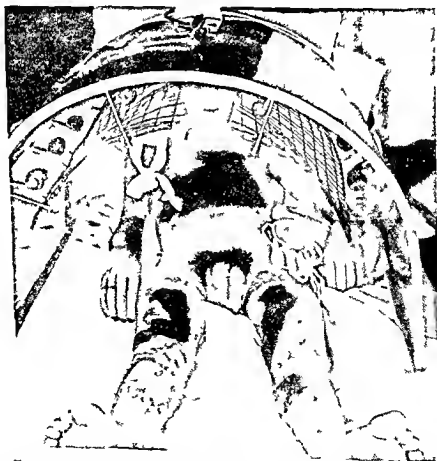


FIG. 6—Extensive burns of trunk and extremities treated with tannic acid. The tan can be seen on legs and abdomen. No dressings were used; the patient was nursed under a heated cradle.



## *The Treatment of War Burns*

*Burns of the Hands*—There can be no doubt whatever that the best preliminary dressing for burns of the hands is a saline bath. The hands should be immersed in a bath twice a day and the patient encouraged to move his fingers in the bath. A saline pack is applied after the bath and this is kept moist and allowed to fall off in the next saline bath. By such a process trauma is reduced to a minimum and there is no pain from changing the dressings. After three or four days of this treatment triple dye is used and when this begins to loosen in ten or twelve days



FIG 7—Third degree burn of the hand treated with tannic acid. Note the attenuated fingers and fixed flexion. A result due to the unyielding tan

the burnt area will be found completely healed (Figs 10 and 11)

Saline packs however cannot be given as a first aid dressing and so the majority of cases of burns of the hands have to be treated with a gentian violet jelly, excellent results have been obtained from this treatment. Many a time we have seen members of the trawler crew who have been bombed at sea and burnt either by bomb flash or scalded by a burst steam pipe in the engine room, arrive in port four days after the





FIG. 8.—Third-degree burn of hand treated with tannic acid. Terminal necrosis of the fingers can be seen.

FIG. 9.—Skiagram of hand depicted in Fig. 8, showing necrosis of the terminal phalanges.







FIG 10—Mixed burn of the hand of an airman. Photograph taken just prior to treatment with triple dye



FIG 11—Mixed burn of hand treated with triple dye. Three weeks after injury. Same case as shown in Fig 10



attack. The prompt use of gentian violet jelly and its repeated application has allowed these members of the crew to carry on with their work until they reach port.

Burns of the third degree in which the whole thickness of the skin is destroyed, should be treated with saline baths if possible and then early skin grafting. Sepsis must be eliminated at all cost because of the contractures that are bound to follow. An excellent dressing for burnt hands is "tulle gras" or "jelonet" or "nonad tulle"; all these are made



FIG. 12.—Mixed burn of face treated with triple-dye.

of woven open-mesh gauze, saturated with petroleum jelly and balsam of Peru. These dressings are vitaminized and sterile and are packed in suitable tins. After soaking the hands in a saline bath for an hour the burnt area is covered with one of the sterile vitaminized dressings over which is placed some sterile gauze wrung out of normal saline solution. This saline gauze is replaced every two hours without in any way interfering with the underlying dressing. It is important that the superficial saline dressing should not become dry, and that the dressing should not stick. The hands are placed on wire splints in a position of rest with



## *The Treatment of War Burns*

slight dorsiflexion of the wrist and slight flexion of the fingers. Two or three saline baths are given each day and the dressings are allowed to float off in the bath thus causing no pain to the patient or trauma to the healing wound.

If the burn has destroyed the whole thickness of the skin then skin grafting should be undertaken without delay otherwise contractures and scarring will result.

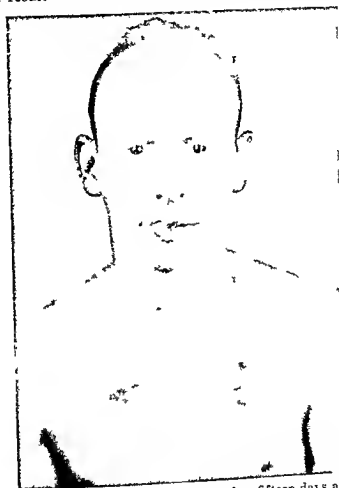


FIG 13—Mixed burn of face treated with triple dye fifteen days after the injury  
Same case as shown in Fig 12

After healing has taken place it is very important that the newly formed skin should be adequately nourished and to this end some lanoline is rubbed into the area every night. This natural wool fat has a wonderful effect on the skin, it causes it to become thicker and more supple and increases its blood supply. It is a pity that the after treatment of burns has been so neglected in this respect. Theunction of lanoline should be continued for fully three months after the healing of the burnt area if good results are to be obtained.



After the envelope has been applied irrigation with hypochlorites is given twice or three times a day (Figs 14 and 15) Between irrigations the wound is left undisturbed This method has some definite advantages in the treatment of war burns They are

- 1 It can be easily and quickly applied
- 2 The treatment is painless, there are no dressings, and the patients do not lose confidence or become depressed
- 3 Rapid epithelialization takes place and can be seen through the envelope Skin grafting can be performed at any time after irrigation with saline solution instead of hypochlorites
- 4 The envelope allows of free movement of the limb without the fear of pain
- 5 In the difficult cases where fractures exist as well as burns, this method appears to offer a solution Treatment of ordinary compound fractures has proved successful

*Extensive War Burns*—A proportion of war burns involves a large area of the trunk and extremities Such burns if they can be treated immediately in hospital should be given a continuous constant temperature saline bath The whole body is immersed in a bath filled with 0.9 per cent saline solution The temperature of the water is controlled by a thermostat The patient is left in the bath for an hour and then carefully removed to a heated, tented bed and the burnt areas are covered with a layer of tulle gras over which is placed some warm wet saline gauze rolls The gauze should be frequently moistened with saline solution so that the dressing never becomes dry Quite a number of the civil and service hospitals have installed these continuous saline baths because they have proved of real importance in the treatment of extensive burns, especially those in which the whole thickness of the skin is involved When the burnt area becomes covered with granulation tissue then the baths can be discontinued and skin grafting carried out

*Electrical Burns*—These are not uncommon in wartime and they are due to broken cables, short circuits and the like resulting from gun fire or bombing attacks While a certain number of this variety of burn prove fatal yet a large number recover if the initial shock is treated adequately The appearance and size of electric burns will vary with the shape of the object carrying the electricity, but usually they are circular or elliptical areas (Fig 16) The color of the burnt areas is grayish white, with a slightly raised periphery, a depressed center, and no surrounding area of hyperemia They look glossy, feel smooth like parchment and when on the fingers, result in the complete obliteration of the papillary lines over the area they occupy By far the best treat



## *The Treatment of War Burns*

ment for these electrical burns is excision and full thickness skin grafting. Small electric burns require nothing more than the application of some gentian violet jelly.

### **Burns Due to Chemical Warfare**

1 *Mustard gas burns* are very insidious and take a long time to heal so causing a long incapacity on the part of the patient. During the last war mustard gas was the most effective chemical agent used and it was a great casualty producer. It may be that in this war this gas will



FIG. 16—Large electrical burn of the anterior surface of the elbow. This was excised and skin grafted.

be used in the form of a spray from low flying aircraft. Mustard gas in the pure state is a clear oily fluid with a slight mustard like odor. It has great powers of penetration and will soak through clothes and boots and cause a burn. On the skin the liquid mustard gas is not immediately painful and during the interim period before pain is caused the liquid penetrates the tissues rapidly yet it may be some hours before an actual burn is seen clinically and marked itching ensues. There is





↑  
FIG 17—Phosphorus  
burn of face Appearance on admission to  
hospital



FIG 18—Phosphorus  
burn of face a week  
after injury Same  
case as shown in Fig  
17



## *The Treatment of War Burns*

no absorption of the liquid into the general circulation and primary shock is absent. During the first twenty four hours a large blister forms at the periphery of the burn and if not incised will burst of its own accord. In the absence of sepsis there is little constitutional disturbance but if sepsis does occur it may be very severe. Treatment of course demands the complete decontamination of the patient including the burn.



FIG 19 —Phosphorus burn of face three weeks after injury showing complete healing. Same case as shown in Figs 17 and 18.

The clothing must be removed and the whole body should be washed thoroughly with bleaching powder solution (60 gr to a pint). The burn area is then dried and treated with gentian violet jelly or triple dye. Healing is slow and sometimes as long as six or eight weeks elapse before sound healing has occurred.

2. *Liquid lewisite burns* may occur as separate entities or they may result from a mixture of mustard gas and lewisite. Lewisite is a heavy oil which is both a lung irritant and a vesicant. Penetration of the skin



by lewisite is much more rapid than that of mustard gas. Erythema of the skin after a lewisite burn appears within thirty minutes and vesication is developed within twelve hours. The lewisite blister is more sharply defined than that caused by mustard gas and contains an opaque fluid in contradistinction to the clear limpid fluid found in the mustard gas blister. Treatment consists in complete decontamination as with mustard gas and a hot bath. Hydrogen peroxide should be applied to the burn area followed by triple dye.



FIG 20—Crude nitric acid burn of face. Two days after injury



FIG 21—Crude nitric acid burn of face three weeks after injury. Same case as shown in Fig 20

3 *Phosphorus Burns*—A small number of such burns have been treated in the present war. They result from the backflash of incendiary bombs containing phosphorus. Some are extensive whereas others are small and due to the presence of a fragment of shell containing this substance (Figs 17 18 19). Such small burns are liable to become deeper as the phosphorus continues its thermal action on the tissues. As a first aid treatment a solution of 2 per cent copper sulfate should be applied. This combines with the phosphorus and produces an inert chemical substance so preventing any further damage. After the copper sulfate solution has been cleaned off with gauze some triple dye is sprayed on the burnt area.





FIG. 22.—Burn of hand six months after injury, showing attenuated skin with engorged blood vessels. Skin grating should have been performed in this case.



FIG. 23.—Keloidal scars of hands and fingers. Photograph taken six months after a mixed burn of the hand. Early skin grafting would have prevented this deformity.



4 *Crude Acid and Alkali Burns*—A fair proportion of burns due to strong acids or alkalis have been caused because of the repeated bombing of factories in this war. In a series of cases seen by me the patients were treated by immersion in running water followed by the application of triple dye (Figs 20 and 21). In almost every case it is the hands and face that are burnt because the clothing itself is protective.

5 *Phosgene Burns*—These are quite superficial and cause an erythema or brown staining but are quite insignificant in comparison to the rapidly fatal syncope produced by this gas.



Fig. 21—Keloidal scarring of arm and forearm eight months after an extensive second-degree burn. The immediate result was excellent. X ray therapy greatly improved the condition.



### *The Treatment of War Burns*

The odor of phosgene is quite characteristic and resembles that of new mown hay, and when recognized a gas mask should be put on at once and the recumbent position immediately adopted. The burn itself should



FIG 25—Antiflash outfit including gas mask

be treated with sodium bicarbonate solution (3ii ad Q) and then dried after which gentian violet jelly can be applied.

*Final Assessment of War Burns*—It is a great pity that a "follow up" of all burn cases has not been instituted in civil hospitals as is the case in the Royal Navy. It is most important to follow up patients suffering from war burns, because the medical officer may be very pleased with the result of his treatment when the patient is discharged from



## War Medicine

hospital and yet in six months time the newly formed skin may have become keloidal and contractures may have taken place (Figs 22, 23, 24) Further, the patient may be able to do his full work during the warm summer months, but in the cold of the winter the thin skin of the backs of the hands or the ears may crack and fissure and chilblains may form thereon, necessitating treatment and even invaliding from one of the fighting forces This is a serious and significant point as men of the



FIG 26—Antiflash outfit for facial protection, the goggles and mask are held in place by elastic bands



FIG 27—Antiflash protection outfit, side view



## *The Treatment of War Burns*

fighting services may have to go into cold climates, and in the Navy be exposed to bitter winds and rapid changes of temperature.

*Protection Against Burns.*—In the Royal Navy and in the Royal Air Force the vast majority of war burns involve the face and hands. In the Royal Navy this important fact has been appreciated since the battle of Jutland in 1916. At the present time an antiflash clothing for the head and hands is now served out to every fighting ship for the use of officers and men who are exposed to gun-flash or bomb-flash, and has resulted in a marked reduction in the number of burns. This outfit (Figs. 5, 26, 27) can be used in conjunction with a gas mask and is simple and easy in its application and does not impede the usefulness of the men at action stations.

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# AN EXPERIMENTAL STUDY OF THE WOUNDING MECHANISM OF HIGH-VELOCITY MISSILES

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The fact that the amount of tissue destruction caused by small high velocity bomb splinters may be out of all proportion to their size has been recognized for some time. More obvious explanations of the disproportion between size of wound and size of missile—for example, that it is due to the irregular shape of the splinters and to their rotary movement (Wilson 1940)—appear inadequate to explain the phenomenon, and it was therefore suggested (Zuckerman, 1940) that a more reasonable interpretation lies along the lines suggested by Cranz and Becker (1921) in their analysis of the effects of high velocity missiles in soft media. If the physical explanations of Cranz and Becker are applicable to splinter wounds in flesh it would appear that the destructive effect of a small splinter is due to the motion imparted to the soft medium through which it passes, as a result of which the tissue is moved away violently from the track of the missile, an effect being produced similar to that of an internal explosion.

Observation also shows that splinters have little rotary effect in those media in which their effect has been studied. It has been found, too, that non spinning projectiles fired from a smooth bore have an explosive effect in media such as mud (Cranz and Becker). It is thus improbable that the damage which occurs in the neighborhood of the actual track of a splinter would be seriously altered by any peculiarities of shape or by any rotation. On the other hand shape and rotation could undoubtedly have an effect on the track itself.

The experiments described in this discussion have been designed to test this interpretation.

## Method

The investigation was carried out on rabbits and on blocks of 20% and 5% gelatin. The former dilution was chosen as it corresponds to the dilution of protein in the body.

With the facilities available to us it proved impracticable to devise a splinter gun capable of firing irregular shaped fragments of metal at high velocities in such a way that they could be accurately aimed. It



## *Experimental Study of Wounding Mechanism of High-Velocity Missiles*

was also impracticable to perform the experiments with model bombs. Accordingly a gun was devised (by Colonel P. Libessart of the Free French Forces) capable of firing, with a cordite charge, a 3/32-inch steel ball weighing 53 mg. at velocities varying between 500 and 5,000 f/s. The choice of this standard missile was to some extent arbitrary. In weight it corresponds to a very large proportion of the splinters which are shot off from any bomb or shell. It is possible, by means of relationships that have been worked out in other fields of ballistic study, to equate approximately some effects of the ball with those which would result from the penetration of any irregular-shaped splinter.

The velocity of each shot was measured by means of the Boys spark-photography method. The essential feature of this method is that the missile cuts a wire forming part of an electrical circuit, and thereby, through a relay, discharges a condenser across a spark gap. By using 10,000 volts enough light is obtained from an exposure of less than 1 microsecond to throw a shadow of the missile and target upon photographic paper. The impact and residual velocities of the missile are measured from the sound waves which are thrown off and which are photographed on the paper. By varying the interval between the impact of the missile on the target and the cutting of the wire, shadowgraphs of the target can be obtained at varying times after it is hit. Using identical targets for successive shots, it is thus possible to photograph the successive changes which take place in a target during the fraction of the second after it is struck.

### **Results**

Blocks of gelatin 4 cm. by 5 cm. by 5 cm. were made by pouring a warm 20% solution of gelatin in water into moulds. Figs. 1 to 6 show silhouettes of the gelatin at varying times after the ball hit the front face of the block. Before each shot was fired control shadowgraphs were made, and these are outlined in each figure to give a measure of the distortion undergone by the gelatin block after its penetration by the ball. The magnification of the stages in each series of photographs varies; the dotted outline in each case, however, represents the same size of target. Unfortunately it was impossible to follow the cycle of changes through to the end because the blast of the gun, which follows behind the missile, forms a shadow that obliterates the gelatin block in the photograph. The blast actually helps to blow the gelatin block away. Each target, was, however, recovered immediately after the shot was fired.

It will be seen that as soon as the ball enters the target a tail splash



develops. This increases in size in the interval taken by the ball to traverse the block. As the ball emerges it pushes before it a head cone which it ultimately leaves. This is the only distortion which occurs during the few microseconds taken by the ball to pass through the target. Immediately after complete perforation has been achieved, however, the block of gelatin undergoes considerable expansion, until it becomes some three to four times its original volume. In spite of this distortion the blocks return to their original size and shape. The only permanent visible effect of the shot is the small thread like track made by the passage of the ball. This track is the same in appearance as that caused by pushing a needle through the block. Occasionally a few small bubbles of air and small radial fractures may be seen in the track. Experiments with similar blocks of 5% gelatin gave the same result.

A corresponding series of photographs were made of cylindrical 20% gelatin blocks shot diametrically. The changes demonstrated were the same as those shown by the rectangular blocks. In this series of observations shadowgraphs of the same target were made simultaneously in a plane at right angles to the usual plane of photography. This was done by reflecting by means of a mirror, the light from the spark on to recording paper placed beneath the target. These additional shadowgraphs showed that the size of the target increases in all directions.

A third series of observations on identical cylindrical blocks of gelatin enclosed in a skin made of the inner tube of a bicycle tire showed that the distortion for similar time intervals after the first impact of the shot was considerably reduced, the reduction presumably being due to the resistance of the skin to the expansion of the gelatin.



FIG 1—30 microseconds after impact ( $\times 0.70$ ) Direction of shot  $\rightarrow$



FIG 2—126 microseconds after impact ( $\times 0.68$ ) Direction of shot  $\rightarrow$

Figs 1 to 6 show shadowgraphs of rectangular gelatin blocks 4 cm by 4 cm by 5 cm during and immediately after penetration by a 3/32 inch steel ball travelling at velocities between 700 and 1 000 m/s (2 296 and 3 280 f/s). In all the figures the dotted lines show the outline of



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a shadowgraph of the target immediately before shooting

Fig 7 shows the outline of the hind limb of an anaesthetized rabbit immediately before and a shadowgraph of the limb 550 microseconds after the impact of the steel ball. The limb shows the same type of

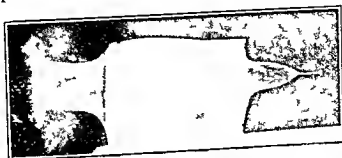


FIG 3—207 microseconds after impact ( $\times 0.64$ )  
Direction of shot  $\rightarrow$

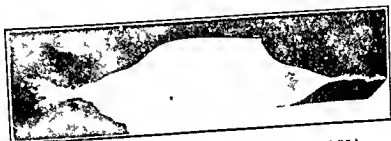


FIG 4—300 microseconds after impact ( $\times 0.56$ )  
Direction of shot  $\rightarrow$



FIG 5—840 microseconds after impact ( $\times 0.48$ )  
Direction of shot  $\rightarrow$



FIG 6—860 microseconds after impact ( $\times 0.47$ )  
Direction of shot  $\rightarrow$



distortion as the gelatin blocks. At the time of the shadowgraph the ball had completely traversed the limb



FIG 7—Shadowgraph of rabbit's hind limb taken 550 micro seconds after impact. The  $\frac{3}{8}$  inch steel ball passed through the hamstring muscles. The impact velocity was within the same range as the previous shots ( $\times 0.56$ )  
← Direction of shot

#### Discussion

The changes which occur in the gelatin blocks can only be explained as being due to the formation of a cavity within the blocks with explosive violence. As the missile passes through the block it imparts motion to the particles in its track, and these fly off radially, imparting their momentum in turn to further particles (and so on), the whole process occurring with explosive violence. In this way a central cavity, the pressure of which is presumably sub atmospheric, is formed within the target. The peak of the change occurs after the missile has completely penetrated the target. It can be estimated from the series of tests on the 4 cm by 4 cm by 5 cm gelatin blocks that 800 microseconds after impact the gelatin is distributed in a peripheral layer averaging about 0.5 cm thick and surrounding a central cavity approximately 5 cm in diameter. The stresses imposed on the gelatin when struck must be great compared with those that it would be able to resist for a period longer than that in which the cycle of changes occurs. Nevertheless, it is surprising that there is so little evidence of damage in the gelatin blocks when the cycle of distortion is complete.

It has been shown experimentally that the cavitation caused in soft



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clay by high-velocity missiles is not due to the pressure of air drawn in behind the bullet (see Cranz and Becker). Thus there is no cavitation when a bullet is fired into a clay target down a prepared tubular track with a diameter slightly greater than the calibre of the bullet. Furthermore, the explosive effect is also observed when a bullet is fired through a soft medium kept in a vacuum. But, on the other hand, the cavitation which occurs in a soft medium is almost certainly responsible for the drawing in of air, some of which may be pushed out again when the target returns to its previous shape. Air may be left in the track, as is shown by the subsequent presence of a few minute bubbles in the gelatin blocks. Small bubbles are also sometimes observed in splinter wounds in flesh.

The fact that the shadowgraphs of animal limbs are essentially similar to those of the gelatin blocks suggests that precisely the same changes occur in human or animal tissues that are traversed by high-velocity missiles. The distortion to which they are subjected can only be likened to that of an internal explosion, and at the height of the deformation, which occurs after the missile has left the part, the tissues must be stretched around a central cavity of relatively large dimensions. Under such conditions it is obvious that structures at great distances from the track of the projectile can suffer damage.

It is a common clinical observation, and one which we have confirmed experimentally, that minute puncture wounds, caused by small bomb splinters, in the skin on the entry and exit surfaces of a limb or other part of the body are often the only external signs of relatively serious internal injury. Our experiments with rubber-coated cylindrical blocks of gelatin provide a parallel to this observation in so far as only minute punctures are made in the rubber covering, in spite of the considerable immediate distortion of its contents. On the other hand, when the steel ball is fired at high velocity at the skinned limb of a dead rabbit or at a slab of meat a large crater is formed in the flesh on the entry side, and the destruction is much greater than in a corresponding part covered by skin.

The explosive character of the forces set up by the high-velocity ball in its passage is manifested not only by the amount of tissue destruction caused but also by the fact that we have often observed comminuted fractures of the femur of a rabbit even when the path of the projectile lay more than 1 cm. from the bone. These fractures can be explained by the fact that bone is relatively non-elastic, and that it fractures as a result of the stresses to which it is subjected by the explosive formation of the cavity along the path of the missile. In the same way we have



found that heavy glass plates placed in contact with the gelatin targets, and at a distance of 2 cm from the track of the ball, are shattered. It would be of interest to discover whether similar indirect fracturing of bone occurs in war casualties

In contrast with bone, highly elastic structures such as arteries, veins, and nerves are apt to escape injury in wounds caused by high velocity missiles. Thus post mortem examination of exposed animals shows that larger vessels and nerves may run intact through regions in which muscle and smaller vessels are often much damaged. It is only rarely that we have observed relatively severe haemorrhage from larger arteries in wounds caused by the ball travelling at 2,500 f/s and upwards, whereas the impression so far gained in our work is that such haemorrhage is not uncommon in wounds caused by the ball when travelling at, for example, 1,500 f/s

In further experiments we have found that a steel ball, travelling at a velocity of 2,400 f/s through a gelatin block in which is embedded an excised strip of artery containing fluid maintained at a pressure of 100 mm Hg, will not rupture the vessel, in spite of the distortion of the block, except when the ball actually hits it

Although larger nerve trunks appear to remain anatomically intact in high velocity wounds, it should be remembered that they have momentarily undergone considerable stretching around the cavity caused by the missiles. This stretching may be a cause of the transient paralysis and analgesia which is sometimes said to occur as a result of bomb splinter wounds, for it is known that a nerve can lose its conducting properties for some time after such distortion

#### Summary

Experiments suggest that the disproportionate degree of tissue destruction caused by small high velocity bomb splinters is due to the fact that particles lying in their path are thrown radially with sufficient violence to leave a central cavity around which tissues at some distance from the track are momentarily stretched. While blood vessels are usually elastic enough to experience this strain without anatomical and apparent functional injury, and nerves without obvious anatomical injury, bones are often broken at some distance from the track

Our warmest thanks are due to Colonel P. Libessart, Free French Forces, whose design of the gun and assistance with the photographic technique made this work possible. We also wish to express our gratitude to Miss B. Hunt for her technical assistance

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# WAR WOUNDS AND ANEROBES

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## History

Before we take up the study of anerobes involved in war wounds let us view the history of the entire anerobic realm.

In 1776 Spallanzani discovered that certain bacteria could live in an anerobic environment. In 1861 Pasteur recognized the fact that certain organisms, were able to exist and multiply in the absence of free oxygen.

The first of the pathogenic anerobes to be discovered is the *Leptothrix buccalis*. Robin isolated and described it as early as 1847. In 1879 it was isolated by Trevesan. Frankel (1882) Michelson (1889) and Epstein (1900) observed leptothrix in connection with inflammations of the mouth and pharynx. Vignal and Arustamoff successfully isolated this organism.

Obermeier engaged in the study of relapsing fever, isolated an organism, which he called the spirillum of relapsing fever. This occurred in 1873. Little further work was done on this spirillum until thirty years later. From 1904 to 1908, various forms were discovered, among them the spirocheta duttoni, by Dutton and Todd in 1905, the spirocheta dochii, by Novy; the spirocheta carteri by Mackie, the spirocheta Vincenti by Blanchard. There are several types of relapsing fever and it is not yet known, which types of spirochetes are responsible for the various types of the disease.

Schaudinn (1905) in his researches on spirocheta pallidum, very often found spirillum of very similar morphology. This spirillum is the spirillum refringens, found in the mouth, tonsils, in ulcerating lesions, in smegma and in venereal warts. Noguchi (1913) in cultivating various bacteria, taken from lesions of the external genitals, discovered a new species, which he called spironema phagendis. Another similar anerobic spirochete had been discovered in 1912 by King & Baeslake, they called it the spironema hyos.

Framboesia tropica, a disease occurring in tropical and subtropical countries, was studied by Castellani (1905). He isolated from a large number of cases a spirochete which was named spirocheta pertenuae. It occurs in the cutaneous papules and ulcerations accompanying the disease. Von dem Borne, repeated Castellani's investigations two years later, and confirmed the facts stated by Castellani.

In the same year Schaudinn and Hoffmann, carried on a series of investigations, with syphilitic patients, examined primary syphilitic in-



durations and secondary enlarged lymph nodes, and discovered a spirochete which had not been described and which was found in infected syphilitic patients, in a great proportion, and which was not found in uninfected patients

Next to the *spirocheta pallidum* comes the *Clostridium tetani*, in interest from the standpoint of pathogenicity. Lockjaw had been known for many centuries but it was not before 1883, that the causative agent of the disease was discovered. Carlo and Rattone in 1883 discovered it in the pus from a cutaneous lesion of a tetanus patient. They called it the bacillus of lockjaw. Nicolaier (1884) and Kitasato (1889) each carrying on investigations on tetanus, isolated and described a bacillus, which is believed to be identical to the one described by Carlo and Rattone.

Van Ermergen (1896) investigated a portion of a pickled ham, the ingestion of which had caused disease of 34 persons, ten of them very seriously. He isolated an organism, which he called the bacillus botulinus. His work was confirmed by Romer (1900). In 1915 Nevin discovered another type of *Bacillus botulinus* which he called *Bacillus Botulinus B*.

Babes Vincent and Plaut are the chief workers on the disease known as Vincent's Angina. In a throat smear of a patient, suffering from Vincent's Angina, Babes in 1889, isolated the bacillus fusiformis.

A bacterium found in the stools of nursing children is the bacillus bifidis, discovered by Tissier in 1900.

Less important are the following. The lymph node anerobic bacillus, closely related to the bacteria group, also called the *Corynebacterium* discovered by Torrey in 1916. The bacillus egypticus discovered by Stoddard in 1919. The multifementans tenalbus or *clostridium multifementans* also discovered by Stoddard in 1919. The anerobic pseudotetanus bacillus, or *clostridium tetanomorphum*, discovered by MacIntosh & Fildes in 1917. *Actinomyces Nectophorus* discovered by Löffler in 1884, and the *treponema mucosum* of Noguchi (1913).

A very extensive study was made of the anerobic organisms associated with traumatic injuries, during World War I. Most of the bacilli had been discovered long before the outbreak of the war, but it was during the war that we learned so much about them. The first of these organisms to be discovered was the *Vibrio Septique* of Pasteur and Joubert (1877). B. Welchii found in gas gangrene usually in civilian cases was first discovered by Welch and Nuttall (1892). This bacillus has also been called the gas bacillus, bacillus perfringens, and *clostridium welchii*. Another bacillus of this group is *B. Oedematiens*, which infected a large number of wounds, according to the discoverers, Wein



berg and Sequin (1915). In the same year Weinberg and Sequin isolated *B. fallax*, a slightly pathogenic anaerobe. The following year they discovered the *B. histolyticus*, an intensely proteolytic anaerobe found associated with the anaerobes in war wounds. In 1889, twelve years after Pasteur had discovered *Vibrio Septique*, Cornevin, Arloing and Thomas found a bacillus, which they called the *Bacillus Chauvei*, the bacillus of Symptomatic Anthrax or blackleg.

Another organism that Weinberg and Sequin claim to have occurred frequently in war wounds is the *B. Sporogenes*, discovered by Metchnikoff in 1908. In putrid wounds is occasionally found *B. Putrificus* discovered by Bienstock (1884). The *B. Sporogenes cadaveris* of Klein is perhaps the same as *B. putrificus*. Tissier and Mortally have found this organism present in putrid meat. The bacillus *oedematiens* of Weinberg and Sequin is similar to, but not identical with *oedematiens* II, or *Bacillus* of Novy, discovered by Novy in 1894.

### Technique of Isolation

Anaerobic bacilli are comparatively difficult to isolate. It was not until World War I, that efficient methods for the isolation of anaerobes was developed. The early workers usually were working with several organisms, when they thought they had a pure culture. MacIntosh & Fildes developed a good method for their isolation by using a technique, which involved repeated plating of the anaerobic bacilli. Veillon's method was used by some workers. This consisted of inoculating agar shake tubes with varying dilutions of material. The tube is then filed through at the level of the colony, and the colony is then fished. The best method is Barber's method. (Developed by Barber in the laboratories of the Rockefeller Institute.)

In Barber's method a pipette is used to pipette out the colony. Barber claims that his method is not as time consuming as the older methods, and permits the observer to make further observations on anaerobiosis, variability, motility, rate of growth, and behavior in a medium of small sowing exactly known, than the older methods allowed.

An isolation chamber is used 7 cm. long, 3.25 cm. broad and 2 cm. high, which gives sufficient room, and allows the use of a large cover glass, 60 by 35 mm. The cover glass must be heated very clean, because it may be used for growing colonies on it. It is carefully cleaned, and smeared with vaseline washed with hot water and alcohol, and wiped with a clean cloth. This leaves a very thin film on the glass. If sterilization is necessary, it should be done over a flame of low temperature, so as not to melt the vaseline. The point of the pipette should be made



very fine, just large enough to permit the entrance of organisms It should be about 5 micra in diameter

With the aid of a microscope, a small droplet is pipetted from a coverslip containing a thin film of the solution, containing the organism to be isolated The droplets pipetted off should then be examined under oil immersion This will insure the purity of the culture insofar as organisms visible to the oil immersion lens are concerned Invisible organisms cannot be guarded against

The isolated organisms are then transferred to test tubes, or grown on cover glasses and then transferred A fresh pipette is used for each organism, and the organisms are separately transferred to test tubes Each new pipette has the tip sterilized, by supplying same with a small amount of sterile broth before use This aids also in washing the bacilli well into the tubes, in the case where bacilli adhere to vaseline on the outside of the pipette In washing the bacilli out the technician must be careful not to blow any air into the culture The pipette method is used upon seeding material isolated by the usual means Air was removed by pumping in oxygen or by heating, the culture being covered by a layer of vaseline  $1/5$  to 2 cm thick, which prevents access of air For growing spores in hanging drops, Barber used the following method A shallow moist glass chamber, 45 mm long, 25 mm broad and 2 mm deep, is made The isolated spores are arranged on a cover glass 15 or 2 mm apart, and sufficient media added The under surface of the cover glass with the exception of the central portion containing the isolated spores is then covered with a soft glucose agar culture of *B. pyocyaneus*, about 4 or 5 hrs old The area in the center may be surrounded by a thin paraffin wall to prevent spreading of the *pyocyaneus* The bottom of the moist chamber is also supplied with a similar layer of *pyocyaneus* culture Pyrogalllic acid and KOH were used by Barber in connection with *B. Pyocyaneus*, but did not offer any advantage Barber made sowings of the following bacilli *B. Sporogenes*, *B. Welchii*, *B. Tetani*, *B. Edematis*, *B. Botulinus*, *B. of Ghon Sachs*, *B. Aerofoetidus*, *B. Putrificus*, *B. Bellonensis*, *B. Tertius*, *B. Fallax*, *B. Edematiens*, *B. Bifermentans*, *B. Histolyticus*, *Vibrio Septique*

Out of 400 one cell sowings of bacilli, he succeeded in producing growth in 62, or 15.5%

He made 211 one cell sowings, using all of the above with the exception of *welchii*, *edematis*, *aerofoetidus* and *fallax* and producing growth in 93, thus getting as a result 44.1% For the bacilli, he used as media glucose broth, serum glucose broth, semisolid glucose agar, semisolid serum agar, firm glucose agar, firm Veillon agar, liver pep



tone agar, minced brain, liver peptone water under vaseline, liver peptone water in vacuum, milk and plain broth. For the spores he used in addition, egg cube and meat, but did not use liver peptone agar or minced brain. The bacilli as a whole grew best on the various glucose media, the spores on the semisolid glucose agar. Barber also found that spores remained viable after exposure for an hour or more, whereas bacilli were much more rapidly affected depending on species. Barber found that *B. Sporogenes* grows very rapidly, *B. Bellonensis* very slowly.

In summarizing Barber made the following statements: "(1) The pipette method has proved a feasible method of obtaining pure cultures of one cell anerobes. (2) Both bacilli and spores may be used as seeding material, but spores give a much higher percentage of positives. Boiling alone affords a sufficient degree of anerobiosis, to the medium, for initiating one cell growth; and semisolid agar is the most convenient form of medium. Exposure to air during isolation apparently has no effect on the viability of spores of anerobes, but young bacilli of some species suffer from a comparatively short exposure to free oxygen."

### Cultural Characteristics

The cultural characteristics of the anerobic bacilli causing gas gangrene will be discussed. We may divide these up into two groups a saccharolytic and a proteolytic as follows: *Saccharolytic*, *B. Welchii*, *Vibrio Septique*, *B. Oedematiens*, *B. Fallax*, *Proteolytic*, *B. Sporogenes*, *B. Histolyticus*, *B. Putrificus*.

*B. Welchii* is a gram-positive, nonmotile organism. In older cultures it may become gram negative. Its length is 4 to 8 micra, breadth 1 to 1.5 micra, straight and usually square. It may be coccus shaped or rod shaped, and has a capsule. It has no flagella, no spores, and is not very strictly anerobic. The surface colonies on nutrient agar, serum agar, or glucose agar are circular in contour. Old colonies are 1 to 2 mm in diameter. Young colonies, that is, colonies about 12 hrs. old are translucent. It ferments the common sugars, starch, and may ferment glycerine and inulin. It does not ferment mannite, dulcitol, salicin. It grows rapidly on meat with a formation of acid and gas. In milk we get what is known as stormy fermentation. Acid and gas is formed with remarkable rapidity in great quantities. No spores. In coagulated serum there is no change, no liquefaction, and spores are formed. In alkaline egg broth an opacity results. Gelatin is liquefied in 48 hrs. in an inoculated tube at 37 degrees Centigrade.

*Vibrio Septique* is gram-positive, composed of slender rolls, strictly



anerobic, has spore formation, is motile, has no capsule. On meat we get a rancidity and gas. On milk, where it is usually found, it causes acidity, produces a little gas and causes clotting. There is no liquefaction on coagulated serum. Alkaline egg broth growth results in opacity, but there is no clotting. It liquefies gelatin. When grown on broth a turbidity forms, which settles to the bottom leaving a clear supernatant fluid. It will ferment glucose, levulose, galactose, maltose, lactose, and salicin. It will not ferment glycerine, saccharose, inulin, mannite, and dulcite.

It may be differentiated from the *B. Chauvii* of Arloing, Cornevin, and Thomas, by the fact that *Vibrio Septique* will ferment salicin, *B. Chauvii* will not.

*B. Oedematiens*, is motile under strictly anerobic conditions, it is a stout rod, 0.8 to 1 micron in length, which is somewhat wider than *B. Welchii*. The rod is lightly curved. Autolysis sets in very early in *B. Oedematiens* cultures. Strict anerobic conditions for good growth are required. In meat we get gas, in milk acid and at the end of 4 or 5 days a clot. Coagulated serum, no change. Broth, a flocculation and a semi opaque cloud. Gelatin is liquefied. The production of acids is feeble in fermentations. It will ferment glucose, levulose, and maltose. It will not ferment glycerine, galactose, saccharose, lactose, mannite, dulcite, inulin, and salicin.

*B. Fallax* is a motile, slender rod 3 to 6 micra in length, has rounded ends and is slightly curved. Gram negative elements are frequent. When colonies are grown those on the surface appear as round, crenated slightly granular. The deep colonies are lenticular, irregular, or bean shaped. It will not digest meat but will form acid. In three to seven days a milk culture clots. With coagulated serum there is no liquefaction. The same is true of gelatin. All strains of *B. Fallax* will ferment glucose, levulose, and maltose, but only a few strains will ferment galactose, saccharose, starch, inulin and salicin.

*B. Sporogenes* is ancillary to the condition of gas gangrene. It is actively motile, slender, forms spores, gram negative in old cultures, gram positive in young cultures, and is not absolutely anerobic. The colonies have a woolly tangled filament structure on the periphery, and have a hard center. The deep colonies are woolly. On meat there is a vigorous growth, with gas formation, an alkaline reaction, and a putrid odor. In milk, a turbidity is formed, which settles out, leaving a clear supernatant fluid, the reaction becoming alkaline. Coagulated serum is liquefied. In alkaline egg broth a flocculent precipitate falls to the bottom and is digested. Gelatin is liquefied. It will ferment only glu



cose, levulose, and maltose. Some of the other organisms ancillary to a condition of gas gangrene are: *B. Cochlearis*, *B. Parasporogenes* (McIntosh 1917), *B. Tertius* (Henry 1917, Rodell as *B. III. Hibler* as *B. IX.*), *B. Tetanomorphus*, *B. Aerofitidus*, *B. Bifermentans*, *B. Putrificus*, *B. Butyricus*, *B. Multif fermentans tenalbus*.

*B. Histolyticus* is motile, rod shaped, frequently arranged in pairs, is 3 to 5 micra in length, and 0.5 to 0.84 broad. Cultural reactions are characteristic for the group. The surface colonies are delicate, flat, crenated, and have irregular edges. In agar the deep colonies are arborescent or coral like with fine wooly ends to the branches. A white deposit of tyrosin follows digestion upon inoculation in meat. Coagulated serum is liquefied and gelatin is liquefied. Glucose, levulose, maltose-fermented.

*B. Putrificus* is strongly proteolytic, gram-positive rod, oval spores, strictly terminal, giving drumstick appearance. Gelatin and serum are liquefied, milk is digested. It is found in gas gangrene and contributes to the putrid odor, but is in itself not pathogenic.

### Power of Resistance

In the classification of anaerobes, we inquire as to their resistance to an oxygen environment. In viewing the bacterial realm, we notice that we have various groups as regards aerobism. To one of these groups atmospheric oxygen is a toxin. This group is the obligative anaerobe group. Barber's experiments showed that the presence of free oxygen stopped growth as follows: *B. Welchii*, 23 min.; *B. Tetani*, 60 min.; *B. Oedematis*, 10 min.; *B. Botulinus*, 6 min.; *B. Sporogenes*, 0 min.; *B. Of. Ghon Sachs*, 6 min.; *B. Aerofitidus*, 10 min.; *B. Putrificus*, 1 min.; *B. Belonensis*, 6 min.; *B. Tertius*, 10 min.; *B. Fallax*, 6 min.; *B. Oedematis*, 17 min.; *B. Bifermentans*, 6 min.; *B. Histolyticus*, 10 min.

No culture has ever been grown absolutely oxygen free, a little oxygen is always present. Anaerobes live symbiotically with aerobes to a great extent, and perhaps acquire oxygen in that fashion.

During World War I it was forcibly called to the attention of the clinicians that the resistance of the bacteria to certain antiseptics did not have the same effect on the bacteria in the wound as it did in the laboratory.

Antiseptics of rapid action, which anaerobic bacteria are unable to resist, are Dakins solution, eusol (hypochlorite solutions) and chloramine T. These antiseptics prevent further growth, even in optimum media. With eusol the following figures will show result of action.



## II *in Medicine*

<i>Time ensl remained in wound</i>	<i>No of colonies developing</i>	<i>No of bacteria per cc of fluid in wound, calculated</i>
5 min	2	200,000
20 min	50	5,000,000
30 min	40	4,000,000
60 min	25	2,500,000

<i>Time chloramine T in wound</i>	<i>No of colonies developing on plates</i>
10 min	No growth after 24 hrs
20 min	Innumerable colonies after 4 days
30 min	Innumerable colonies after 4 days
60 min	Innumerable colonies after 48 hrs

The antiseptics used above are very destructive to anaerobes in the laboratory, but their potency is dissipated in some way in the wound perhaps, by contact with the walls of the wound, its discharges, or both of these factors. By experiments carried on *in vitro* it was discovered that the bactericidal efficacy of antiseptics is lessened in the presence of serum, and that leucocytes have a quenching effect upon antiseptic agents. The values for the concentrations of various drugs to completely inhibit the growth of *B. Sporogeo* are as follows: Iodine 1/500, Chloramine T 1/50, Carbolic acid 1 to 200, Mercuric Chloride 1 to 2,000, Crystal violet in 6,400. For *B. Welchii* the values are as follows: Iodine 1 in 500, Eusol 1 in 4, Chloramine T 1 to 60, Carbolic acid 1 in 200, Mercuric chloride 1 in 2,000, Malachite green 1 in 200, Flavoc 1 to 16,000, Crystal violet, 1 in 1,000. Dye stuffs in general exert an inhibitory effect on the bacteria. The bactericidal dyes lose a great deal of their potency by combining with the fabrics used for bandaging.

Anaerobes and especially their spores are comparatively resistant to dessication. Light is a strong bactericidal agent, but in the case of the anaerobes a completely anaerobic environment will interfere with the bactericidal action of light. Hydrogen peroxide is a strong bactericidal agent.

A hypertonic salt solution is an indirect bactericidal agent, it produces an accumulation of leucocytes. Electric light, X rays and radium light have an inhibitory effect on anaerobic growth. Electric currents applied to a solution containing anaerobes will act as a bactericidal agent. Heat will kill anaerobes.

### Channel of Infection Most Common Source

The point of infection is the wound. Of the various types some are more liable to anaerobic infection than others. The more irregular and lacerated wounds become more highly infected. In the case of a wound



caused by a shell particle acute infection follows for two reasons. The shell particle makes a rougher wound than the high-powered bullet, and the shell bursting on percussion with the ground carries with it as it enters the wound portions of soil, which in highly fertilized districts may be heavily charged with anaerobes. Infection may take on various phases. We may get a localized anaerobic infection in the wound; slowly spreading anaerobic infection in the wounds; gas gangrene of the "group" type, when a single muscle or group of muscles is attacked; gas gangrene of the massive type where a whole segment of a limb is involved; or the fulminating type.

Infection is aided by the following factors: Retention of extravasated blood; interference with the local circulation; the presence of masses of devitalizing tissues; extensive fractures, and comminution of long bones; retention of wound secretions by dressing, pastes or packings. The wound if it has the shape of a cavity with a small surface opening is ideal for anaerobic growth. Delay in the mechanical cleansing of a wound leads to acute infection, as does also the retention of foreign bodies.

#### **Pathogenicity**

In a wound a myriad of factors enter, which determine whether an anaerobic infection will be apparent within an hour, or whether several days will elapse before distinctive features appear. An infection usually takes the following course. The wound has a brownish discharge, composed of broken down blood clots, it is foul smelling and gives off gas. The odor depends on the infecting organism and the stage of the wound. At the very beginning a characteristic smell is absent, but later it becomes foul and acrid. A serous infiltration occurs throughout the intermuscular septa, and connective tissue. The accumulation of the fluid causes a swelling which takes on the appearance of a purplish ring around the wound. The muscle is at first not infected, when infection sets in we have the condition of gas gangrene. The muscle tissue is invaded by the organisms, and gradually digested. If the blood supply is left intact, we are able to see the actual course of infection. The muscle becomes black, friable, and diffuent. Then we get several color zones, first red, then yellow. Contractility is lost and the muscle undergoes changes in coloring, beginning with red and changing to greenish-yellow and then to black.

In another type the blood supply is cut off. The muscle changes color from purplish red to a greenish black diffuent mass. Gas forms first as bubbles between the muscle fibers, afterwards entering the areolar tissues. The gas has a deleterious effect, since it produces pressure in the fascial sheath and constricts the blood vessels. Interference with the blood



supply is very favorable to infection because neither the first nor second lines of defense are given free play

### Toxin Production

B Welchii produces 1 true exotoxin. An antitoxin was first developed by Klose (1916) which was not however as effective as Bergston's. Since B Welchii is the chief organism involved in gas gangrene, an anti-toxin injection will remove the organism causing the most trouble, and will leave the minor gas gangrene organisms alone, among them the *Vibrio Septique* and *B Oedematiens* who come next on the list from the point of infection. B Welchii was isolated by Weinberg and Sequin in 72.80 percent of the cases of gas gangrene studied by them during World War I. Pathogenicity and hemolytic power vary greatly with the different strains of B Welchii. In fatal cases death usually results from a B Welchii septicaemia. Spores are never formed in the animal body.

*Vibrio Septique* has a very powerful toxin. It is a soluble toxin. A specific anti toxin has been developed.

*B Oedematiens* is in general pathogenic, although two non virulent strains have been isolated by Weinberg and Sequin. The lesion caused by *B Oedematiens* is characterized by a whitish, gelatinous exudate and absence of gas. *B Oedematiens* forms a soluble toxin, but does not cause the acute infection that *Vibrio Septique* does.

*B Fallax* is very slightly pathogenic.

*B Sporogenes* was found in 27 per cent of the cases examined by Weinberg and Sequin, it is usually responsible for the foul odor in wounds. This organism is however, not very pathogenic and produces a weak toxin.

*B Histolyticus* is intensely hemolytic, and produces large lesions, but is non toxic, and does not produce acute infections.

*B Putrificus* is actively proteolytic, produces foul odor, and putridity in wounds, and is non pathogenic. The condition of the wound under treatment may become better or worse. If better it heals, the pus is drained and granulation sets in. If the wound becomes worse, the gas gangrene condition rapidly encompasses more area, and we get a condition which demands amputation.

The infection although primarily caused by anaerobic bacilli is usually found to contain aerobes usually streptococcus and staphylococcus. The anaerobes grow better under an environment containing aerobes. Thus to remove the aerobes which are aiding in causing a media favorable to anaerobes we inject some staphylococcus vaccine, or a vaccine made from *M Tetragenus* and streptococcus. The vaccine usually im-



proves the wound. Vaccine gave good results in cases where a condition ensued in which there was a pyrexia, a cessation of the healing process and an unhealthy appearance in the wounds. In the treatment we must be careful of our use of antiseptic, a very weak solution of chloramine T for example will have a stimulating effect upon the organisms.

### **Dissemination within the Body of the Host**

In the case of gas gangrene, the condition is such that dissemination of the infective material to even a comparatively small extent is fatal. The treatment of a wound is determined by the danger of dissemination to a very great extent. If we have the wound in a limb the limb must be amputated if the infection cannot be controlled. We give our antiseptics with the view of preventing spread of infection. Thus when a patient is brought into the hospital, the wound is immediately washed with hypochlorite solution, and we apply eusol, Dakin's solution, or chloramine T. Hypochlorite solution is the most effective means for putting an initial stop to dissemination.

Slough covered wounds are given frequent washings with a .5 per cent salt solution, which causes a liberation of a tryptic ferment upon the disintegration of the leucocytes in pus. An exudation of lymph also ensues. I will give a brief summary of a few cases showing dissemination of the disease. (Gt. Britain Medical Research Council Report Vol. 57, 1920, Pp. 122-150).

I. Bullet entered right thigh, gluteal muscles affected by gas gangrene, no healing, general condition worse—amputation.

II. Gangrene in muscle of leg. Dissemination stopped by hypochlorite applications. Connective tissue repair.

III. Wounded. Was lying on the field for three days, before he was picked up. He was very weak from loss of blood and an infection spread in his leg. He was taken to the base hospital, wound was treated with Dakin's solution, and every attempt was made to stop spread of infection. Infection continued spreading, so leg was amputated above the knee.

IV. He was wounded in the forearm. Incisions were made for gas gangrene. Infection was counteracted. Granulation tissue repair. Muscle was not as efficient as formerly after wound was healed.

V. Wound in right scapula. Incisions made on surface with extra precautions. Easily repaired. This type of wound offers comparatively little trouble.



VII Infection in gluteal muscles, incisions were made into muscle, but did not aid in stopping spread of infection Muscles excised Fever followed and large pieces of necrosed bone were removed from the neighborhood of the sacro iliac joint, which greatly improved the drainage of the deeper portion of the wound The wound progressed wonderfully quickly, granulations springing up from the bottom and filling the cavity, the epithelium also spreading in from the edges When later the concentration of material became great and contraction followed, but was not rapid enough and epithelium stopped spreading, some 45 Steele's grafts taken from the patient's thigh were applied to the granulating surface no special arrangement being adopted A second skin grafting operation two months later when the scar tissue was very pronounced, and the granulations in consequence very bloodless was an almost complete failure However, under massage to loosen the scar tissue, and to promote circulation healing progressed slowly and patient was discharged

VIII Bullet going through and through leaves clean wound, very easily healed

IX Femur fractured Drainage incisions made to curb infection Infection stopped Operation binding bone with metallic thread Operation for removal of metallic thread Wound heals

X Infection attacks to the extent of septicaemia in very weak patient Death

XI Pus from wounds in head drained This condition is very dangerous due to proximity to the brain

XII Repeated amputations Pleurisy set in Death due to either septic thrombosis of the vena cava or septic thrombosis of the inferior or common iliac vein

XIII Wound healing Severe secondary hemorrhage wound opened but bleeding point could not be found due to infiltration of blood and inflammatory exudation Amputation found necessary and performed

In general we may say this about dissemination An infection is started and we have an inflammation Then there is a leucocytic infiltration Necrosis sets in muscle and bone tissue is destroyed there is a lymphocytic infiltration and a putrefied mass is formed in the wound The wound has a tendency to close on the surface and leaving a putrid proliferative mass A flesh wound on the abdomen if severe enough may gain entrance into the abdominal cavity A case of gangrene in the abdominal region is rare due to the fact that abdominal flesh wounds are easily treated Dissemination of infection of a wound of this kind into the abdominal cavity is usually fatal



Thrombosis, embolism, septicaemia often result in cases of gas gangrene, the latter being fatal, the former two leading to a critical condition.

Various complications may arise. In gas gangrene septicaemia, a high temperature is reached (102 to 103 degrees Fahrenheit) and death follows. Very rarely we may get a gas gangrene pyaemia. There is an invasion into the blood stream, secondary deposits of gas gangrene bacilli in various parts of the body, when the tissues have suffered some slight damage as from the introduction of a hypodermic injection, or an infusion of saline, or they may develop in tissues subjected to prolonged pressure as in the buttock, when the patient lies in bed tilted on one hip. The prognosis is extremely bad.

### Clinical Significance

#### A. Diagnosis of the Disease from a Clinician's Standpoint

1. *The physical standpoint:* The physical signs differ according to the type of the disease present. A localized anaerobic infection is distinguished by a foul smelling discharge, mixed with bubbles of gas. If the disease is more extensive, swelling is noted and upon percussion of the swollen area, a tympanitic sound is heard.

By noting the type of wound, we are able to tell whether an anaerobic infection will soon be in evidence. Wounds with imperfect drainage, extensive devitalization, and death of tissue with extravasation of blood, will result in gas gangrene cases. Imperfect drainage is typical in cases where a projectile made a small point of entrance, entered deeply, and was retained. The general condition of the wounded man is also important. Infection develops much more readily in fatigued troops than in fresh troops. An irregular projectile forms a more irregular wound, and may carry bits of clothing, and thus increase the chances of infection. An area with a diminished blood supply precludes active intervention by the protective mechanisms of the body. When a wound becomes infected it is an anaerobic infection, up to the time the muscle is attacked, then it becomes gas gangrene. The muscle becomes black, friable, and diffuent, and the line of invasion is seen. In others we see red and yellow zones or bands. In some our chief symptom is a loss of contractility. The diagnostic features of gas gangrene are pain, crepitation, resonance on percussion, and what is more important severe constitutional symptoms.

The disease may be one of several types. In the first type we have a localized anaerobic infection. In the second type we have slow spreading. In the third, swelling, and a tympanitic condition and crepitation may be



detected. These symptoms become more marked as the disease continues, the skin develops large irregular fibrillae, with blood stained serous fluid. There is a mottling of purple patches, becoming greenish yellow. The muscle becomes dry brown, pultaceous, and finally black with a slimy surface. This third type is called the group type. The fourth is the massive type. Here the blood supply is cut off, constitutional symptoms such as vomiting, rise in temperature, and a rapid pulse are noted. There is a rapid appearance of signs of decomposition. The fifth type is the fulminating type. Severe pain, extensive swelling of the affected part, rapid spread of the disease, and severe constitutional features are the symptoms.

2 *Symptoms* In the early stages pain is very marked, the unusual amount of pain depends upon the increasing pressure within the wound. When the infection becomes established pain increases. There is a feeling of numbness in the superficial parts of the limb. The patient looks distressed and ill. Lips acquire a cyanotic color, the pulse rate is rapid, and the temperature rises 3 to 4 degrees Fahrenheit. There is continuous vomiting. If the disease becomes more rapid, becomes running and uncontrollable there is more frequent vomiting, the extremities become cold and blue, the temperature falls. The mind, however, remains acute even to the end. In the terminal stages some degree of general icterus may be present. Death comes with dramatic suddenness, the specific cause is still unknown, pulmonary embolism is never found in autopsy.

## B. Laboratory Standpoint

The primary infection is largely made up of fecal material bacteria *B. Welchii* and associated anaerobes in symbiosis with aerobes, chiefly streptococcus and staphylococcus. After the healing process had begun and granulation tissue formed no *B. Welchii* were found upon laboratory examination. In recrudescence of bacterial infections after operations the chief anaerobe to be found was *B. Sporogenes*, always in company with streptococci and staphylococci. As soon as a case was brought into the hospital and physical diagnosis was made samples of pus were collected and films and cultures made. The specific organisms causing the infection are thus noted. Weinberg and Sequin give the following figures. *B. Welchii* found in 72.80 per cent of cases. *Vibrio Septique* in 12 per cent of cases. *B. Oedematiens* in 34 per cent of cases. *B. Sporogenes* in 27 per cent of cases.

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# THE TREATMENT OF WAR WOUNDS OF THE BRAIN

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This discussion is designed to cover not only actual gunshot wounds of the brain but also similar injuries due to fragments from shells and from bursting bombs, the latter being probably even more frequent in this war than the ordinary types of wounds from penetrating missiles.

## Prophylaxis

A few remarks concerning what may be done to lessen the severity of head injuries appear to be in order. In the first place, it would be most desirable if all soldiers could go into action with closely cropped hair. This would not only minimize the amount of hair that would be driven into the brain in penetrating injuries but would also prevent a great deal of infection of the lacerated scalp wound from the long hair, which becomes matted with blood and frequently incorporates itself within and contaminates the laceration. Furthermore, the shaving and sterilization of the area around any such wounds would be infinitely easier.

Secondly, tetanus toxoid has been shown to be a most valuable prophylactic agent and should be given to all soldiers and civilians likely to be involved in enemy actions. The usual dosage consists in 1 cc. subcutaneously as a first injection and a second injection of the same amount two or three months later; a third injection after another two or three months is advisable. If it is known that this series of immunizing injections has been complete, 1.0 cc. of tetanus toxoid should be injected subcutaneously at the time of injury; in the absence of complete immunization, 1500 units of tetanus antitoxin should be given immediately in all cases with compound injuries.

Thirdly, the sulfonamides should be given by mouth at the earliest possible opportunity after a compound injury of any kind has been received. An initial dose of 6 gm. of sulfanilamide should be given by mouth if it is possible for the patient to swallow; if the patient cannot swallow, it should be given through a nasal tube. Subsequent doses at four-hour intervals, so that patients receive approximately 6 gm. daily, should likewise be administered.

## General Principles

It must be remembered that all penetrating brain wounds due to shell fragments, bullets, bomb fragments and so forth are compound fractures. One of the greatest essentials is to get these patients to a



hospital or post where complete treatment can be carried out for their wounds at the earliest possible moment. So far as immediate or delayed surgical shock will permit, it is highly desirable that operative treatment when it is indicated, be undertaken within twelve hours of the time of the infliction of the wound, and earlier if possible, since the sooner these wounds can be debrided the less the chance of subsequent infection and thus of complications, which so often either are fatal or produce untoward late effects\*.

It must also be remembered that many patients, especially those who have multiple wounds elsewhere on the body or extremities, may first of all need treatment for serious shock. This must be combated in all possible ways by warmth, hot drinks, infusions of serum or plasma or transfusions of blood, the guarded use of small doses of morphine, and quiet and complete rest so far as this is obtainable. Infusions and transfusions can be carried out while the patient is being operated on, they should not be delayed too long before operation is undertaken. In addition to the care devoted to the wound of the brain, multiple wounds in other parts of the body, such as those of the chest and extremities, should be looked for and treated.

### **Preoperative Preparation**

As soon as possible, stereoscopic x ray films of the head should be taken in the lateral position, as well as in the anteroposterior and posteroanterior positions. The whole head should then be shaved carefully, and a careful examination for multiple skull wounds should be made. A brief neurologic examination is also indicated, since this may be of great value in checking the subsequent status of the patient if complications such as postoperative hemorrhage arise. A small dose of morphine, not over  $\frac{1}{8}$  to  $\frac{1}{6}$  gr., may be given about half an hour before operation is contemplated, but not until all neurologic data are noted and not, of course, if the patient is unconscious or extremely drowsy.

### **Anesthesia**

In almost all cases local anesthesia is the method of choice for gunshot wounds of the skull and brain. This consists of a 1 per cent solution of novocain to which has been added 4 drops of adrenalin (1:1000) per ounce. If the initial preoperative dose of morphine has not been sufficient to quiet the patient a second dose may be given

\* It is possible that with the present more perfect methods of wound debridement together with the use of sulfonamide operation with primary closure may be delayed from twelve to twenty four hours if necessary.



## *The Treatment of War Wounds of the Brain*

during the course of the operation. There are obviously times when local anesthesia cannot be used, namely, when patients are extremely restless and unco-operative, and especially when multiple wounds elsewhere in the body require operation at the same time. In such cases, ether anesthesia or a combination of Avertin and ether is probably the anesthetic of choice. When highly trained anesthetists are available, intratracheal ether or, for short operations, possible intravenous Pentothal may be extremely useful and may perhaps to a limited extent supersede local anesthesia, although novocain for this type of injury is highly satisfactory in the vast majority of patients.

### **Operative Treatment**

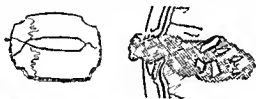
The general idea of operative treatment for all compound injuries is a thorough and careful débridement of the contaminated tissues, together with the removal whenever possible of such foreign bodies and bone fragments as have been retained, without added damage to the surrounding areas. This applies to brain wounds just as it does to those of the extremities, although obvious difficulties arise so far as the brain is concerned because of the undesirability of sacrificing any more normal brain than is absolutely necessary, and because in certain cases more damage might be done in searching for a foreign body, especially for small fragments, than by leaving these fragments alone. Furthermore, the danger of hemorrhage from the deeper portions of the brain must always be carefully considered and prepared for. Again, as a general rule, if patients with gunshot wounds to the brain have been operated on early,—up to twelve hours of the time of the infliction of the wound,—if the operator is satisfied that a complete débridement has been done, and if the patient can be kept under observation by the operator for at least ten days or two weeks, the wound should be closed tightly, without drainage. It is possible that with the use of sulfonamides by mouth or intravenously, together with the local instillation of sulfanilamide or sulfathiazole powder into the wound itself, many more of them can be completely closed than was possible before the introduction of chemotherapy. This, however, is not yet entirely clear, and it is probably well, even with chemotherapy, not to close wounds that have been operated on after the twelve-hour period.

After operation, 1500 units of tetanus antitoxin should be given intramuscularly if a prophylactic dose was given immediately after the infliction of the wound. It is also advisable to give gas-gangrene antiserum to all these patients.



## Wounds Without Dural Penetration

After the usual preparation and sterilization of the scalp around the area of injury the wound should be excised but only far enough beyond the lacerated contaminated edges to take in contaminated tissue. Contused but uncontaminated tissue should not be excised. The instruments used for this excision should then be discarded along with the tissue excised. When there is a linear fracture without positive evidence of depression and when the operator is sure that there has been no intracranial damage the wound may be treated as a scalp wound with primary closure if the wound has been operated on early. If the cranium is depressed one should make one or more small burr openings around



FIG—1—Gutter Type of Wound (Modified from Cushing<sup>1</sup>)

The drawings are diagrammatic representations of this type of wound showing the bone fragments showered into the brain. The photographs show a typical wound before and after operation with primary closure together with the solid area of bone and the bone fragments removed.

the area of depression and then elevate the uncontaminated skull with some proper smooth instrument. Again the instruments used for this bone removal should be discarded. Occasionally an experienced neurosurgeon may consider it practicable to replace bone fragments when early operation and thorough debridement have been performed but such replacement should never be attempted by inexperienced operators. Irrigation of these wounds with physiologic saline solution during debridement is recommended by many neurosurgeons but is deemed inadvisable by others. Sulfanilamide or sulfathiazole powder should be dusted into the wound at the conclusion of the operation.

If the patient shows marked signs of localized contusion of the brain under the area of fracture an area of bone should be taken out whether



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it is depressed or not, and the dura inspected. If the latter is tense and discolored a deep bluish black, signifying an underlying clot, and if the operator is satisfied that his *débridement* has been perfect, the dura should be incised, and the clot evacuated and the dura then resutured completely and carefully with fine silk.

### Wounds With Dural Penetration

Under this heading are included all the more serious types of brain wounds due to missiles of war. In a general way, they may be divided



FIG. 2.—Penetrating Type of Wound. (Modified from Cushing.<sup>1</sup>).

The drawings are diagrammatic representations of this type of wound, with a metallic shell fragment lodged at bottom of track. The photographs show a typical wound from a single large fragment, before and after operation with primary closure, together with the excised area of bone and the bone fragments. Note the "tripod" incisions, which are useful in wounds of this kind.

roughly into five types: the gutter type of wound, in which the missile has plowed through the scalp and often through the bone as well, and in which a shower of bone fragments, together with other debris, such as hair and clothing, has penetrated the underlying brain to varying distances, sometimes going in as far as one of the cerebral ventricles (Fig. 1); simple penetrating wounds, which are usually due to a rather large, single metal fragment that has carried in with it fragments of bone and other debris and has lodged somewhere within the brain, not infrequently penetrating the ventricle and sometimes crossing to the opposite side of the brain from that on which it entered (Fig. 2); penetrating wounds from multiple and often small fragments, particularly bomb splinters—this type of injury has been particularly prevalent in World War II; through-and-through or perforating injuries, which usually have a small wound of entrance and a much larger wound of



exit, with a certain number of bone fragments carried in along the track; wounds involving one or another of the air sinuses, more particularly the frontal and ethmoid sinuses, in which subsequent complications, such as cerebrospinal fluid leak or intracranial aerocele, may develop

*The gutter type of wound and wounds due to a large, single penetrating fragment* The operative treatment of wounds of the first two types may be considered together, since they are essentially similar in most of their aspects and in general require the same type of treatment

After careful excision of the contaminated portion of the scalp, radiating incisions should be made from the area of scalp laceration, usually in the form of a tripod, so that the flaps thus created may be retracted

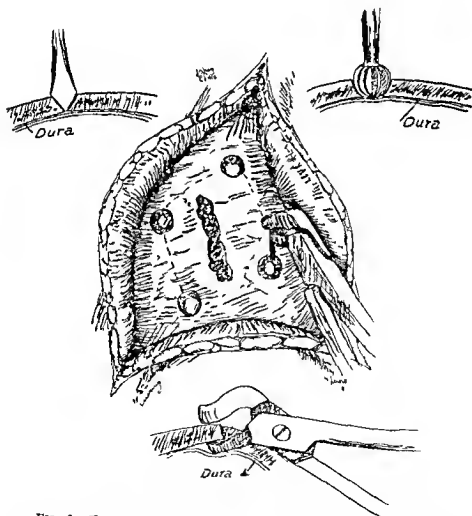


FIG 3—Excision of the Bony Penetration and Depressed-Skull Area by Bone Cutting Forceps after Exposure of the Area by Reflection of the Scalp (Modified from Cushing<sup>2</sup>)



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and an adequate exposure of the fractured area secured. The break in the skull is a relatively small round opening or a rather large, irregular hole in wounds due to a large metal fragment, and the bony defect is a long elliptical area in gutter wounds. Four burr openings are made surrounding this bony defect and including the depressed fracture area, and these openings are connected with bone-cutting forceps, a procedure that enables one to lift out the whole bony area intact and thus to expose the dura with either a small or a large perforation (Fig. 3). At this point, the procedure of choice varies according to whether or not an electrosurgical apparatus, together with adequate suction, is available.

If these two adjuncts are not at hand, a method similar to that employed during the last war, as advocated by Dr. Harvey Cushing, is in

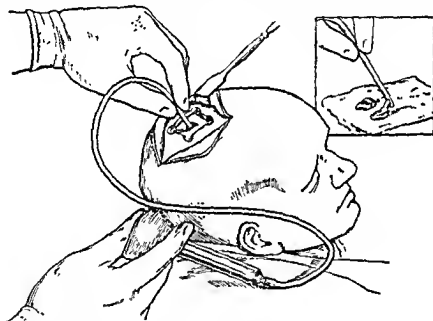


FIG. 4.—Catheter-and-Syringe Method of Débridement of the Track in the Brain. (Cushing.<sup>2</sup>)

The softened, disorganized tissue is sucked out; the bone fragments and other foreign bodies are palpated with the catheter and removed by delicate forceps.

order. If the patient is under a local anesthetic, he is asked to strain or cough, and by this means considerable amounts of clots of semisolid contused brain may be expressed through the hole in the dura, and such material may then be wiped gently away from the remainder of the wound. Indeed small bone fragments may sometimes be thus extruded. A soft-rubber catheter of suitable size is then inserted gently through the hole in the dura, and with this catheter as a means of palpation, bony



fragments along the track of the missile are gently searched for and removed either by gentle suction with a syringe attached to the end of the catheter or by a grasping of the fragments with a delicate forceps and their extraction in this way. Gradually, as the catheter is inserted farther and farther in the track, the area is cleaned out by careful, not too vigorous suction on the catheter, thus, devitalized brain tissue, clots and other debris are drawn up into the catheter itself, the catheter being withdrawn from time to time and such material as has been sucked up into it is then discharged out of the field of operation (Fig 4). In this way, all bone fragments and other debris may eventually be completely removed from the contaminated area in the brain. It is essential to remove every indriven bone fragment in this manner, and it is likewise advisable to remove the metal foreign body, which as a rule is found down at the bottom of the track, if this can be done without undue difficulty and without further damage to the brain. The metallic fragment can sometimes be located with the catheter, and a delicate, alligator forceps can then be inserted and the foreign body picked up and thus extracted. When the metallic fragment is of magnetizable material, it is often useful to insert a long, round ended nail down into the track in the brain so that it touches or nearly touches the metallic fragment. When this has been done, a powerful electro magnet is brought up to the end of the nail, and often the withdrawal of the magnet and the nail also withdraws the foreign body (Fig 5). It is a long tedious process to clean out thoroughly a deep penetrating wound by the means thus described, and when this method is used, it is of the utmost importance not to disturb the dural edge and not to get out into normal brain outside the track created by the foreign body and bone fragments. At the end of such an operation, it is probably advisable to dust sulfanilamide or sulfathiazole powder into the cleaned out brain area, if the débridement is thought to be complete, if the operation has taken place within twelve hours of the injury, and if the patient can be followed for ten days or two weeks by the operator, primary closure should be made.

If an electrosurgical apparatus, together with strong suction, is at hand a somewhat different procedure is preferable to the time consuming and sometimes inadequate débridement possible by the catheter suction method. Although it has not as yet been tried in combat or other war areas, I believe that the following procedure would be particularly applicable in wounds outside the motor and speech areas\*.

\*I am informally a neurosurgeon recently returned from England that this proposed method has been used there with excellent results.



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After exposure of the dura by the means already described, the membrane should be incised to a distance of perhaps a centimeter in a circular fashion outside the area of dural penetration, and then the whole track in the brain should be excised, together with its contained elements, in exactly the same way as a similar wound anywhere else would be excised. With the electrosurgical apparatus, an area slightly outside

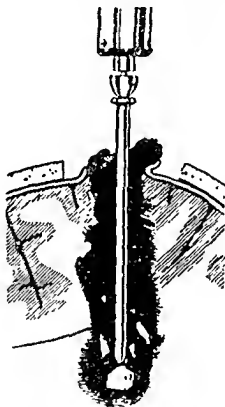


FIG. 5.—Blunt-Nail and Electromagnet Method for Extraction of Magnetizable Metal Bodies. (Horrax<sup>3</sup>; reproduced by permission of the publisher.)

the actual track of the missile or bone fragments should be sealed off, that is, the blood vessels on the surface should be sealed off around this area, and the brain incised in this coagulated area outside the track. Then, by a combination of strong suction, using a metal sucker, and with the electrosurgical coagulating current constantly applied to this sucker, one can clean out the soft brain surrounding the track, together with the clots and other debris (Fig. 6). If larger bone fragments are encountered, they can doubtless be taken out by the strong suction itself, or if they are too large for this, they can be extracted with delicate forceps. In this way, a core of tissue including a small amount of uncontaminated brain outside the track is completely removed by the com-



combination of suction and electrocoagulation, the latter being employed to sterilize the area at the outside of the track as one proceeds. As the core of tissue is gradually removed, one can insert a flat spatula along either side of the cavity created, and thus debride the whole area under direct vision (Fig 7). I am convinced that a much more complete and thorough debridement of all possible elements contained in the track

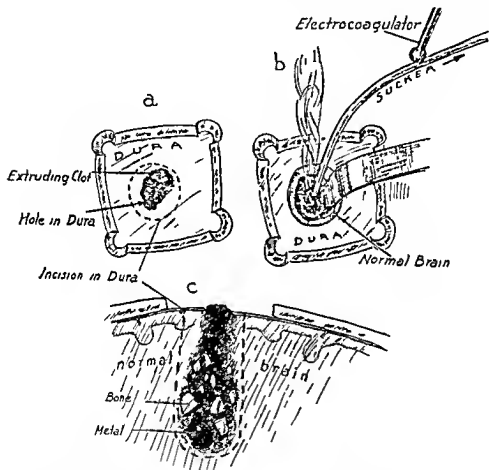


FIG 6—Procedure for Complete Excision of the Contaminated Track of Brain by Electrosurgery and the Suction Apparatus (Horrax<sup>1</sup>, reproduced by permission of the publisher)

Incision of the dura (a) is made outside the track (dotted line), with subsequent removal of the whole area within the dotted line (c), after incision of the cortex just outside the penetrated area (b)

can be accomplished in this way than by the older method. Any possible bleeding set up as this procedure progresses can be rapidly stopped by the electrocoagulation, finally, if a large foreign body requires removal from the bottom of the track, it can be seen and picked out very readily. When ventricular penetration occurs, the ventricle can be inspected



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and any debris removed from it. Again, as in the older method of treatment, wounds that have been completely débrided by the method just described should be closed primarily when patients are operated on within twelve hours after injury, after the local application of sulfanilamide or sulfathiazole powder within the wound.

When patients are operated on after the twelve-hour period following an injury, sometimes after one, two or even three days, the wounds

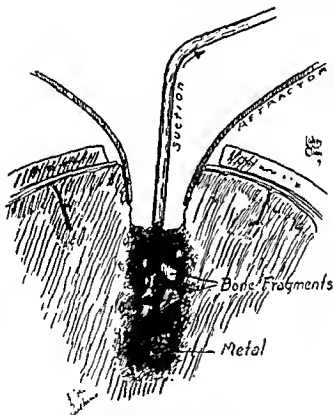


FIG. 7.—Detail of the Procedure Depicted in Figure 6. (Horrax<sup>4</sup>; reproduced by permission of the publisher.)

The brain edges are retracted, and the track cleaned out by suction under direct vision.

show varying degrees of infection, which has sometimes gone on to an extremely foul-smelling herniation or fungus formation of the brain, with bone fragments and other debris extruding through the brain track. These wounds must be opened widely, and additional bone must usually be taken off around the area of penetration so that the dura can be incised in radiating fashion, thus relieving the almost certain constriction that exists at this point and is bottling up the infection inside. All devitalized tissue, bone fragments and other debris should be completely



sucked away down into the track, which should be treated by open drainage of one form or another just like a brain abscess. It is my opinion that probably the best form of drainage in a case of this kind is to insert gutta serena tissue down to the bottom of the track, which is then packed widely open over this tissue with gauze. In any event, the track should be held widely open by some means and in these cases it is probably best not to dress the wound for two or three days but to leave the original dressing with its inserted drainage, in place so that a drainage track becomes firmly established. After that the dressings can be changed either daily or every other day for the sake of cleanliness around the outside of the wound, as healing gradually takes place and infection subsides the drain gradually extrudes and can be cut off a little each day. Finally the area granulates and if the exposure is wide healing can be hastened by secondary suture or by some form of pinch grafts. If a wide area of bone has been exposed, it is sometimes an excellent plan to make perforations over this exposed area down to the diploe from which granulations spring up and cover the bare bone much more quickly than if the granulating process were allowed to proceed merely from the edges.

*Multiple wounds made by small fragments* It has been shown by British neurosurgeons during the present conflict that a very common type of head injury under existing conditions is the spraying of multiple small splinters of bomb casing into various parts of the body, including the head. These splinters are usually quite small and because of their high velocity are almost red hot when they enter the body. Thus they are sterile and such material as may be carried in with them is probably rendered sterile. It has been found that much the best policy with these small fragments is to let them alone rather than to try to extract them operatively. Naturally the scalp wound should be inspected and may need some simple form of attention either simple debridement and closure or perhaps only a simple dressing.

*Through and through wounds* These wounds are usually made by machine gun or rifle bullets that have passed from one side of the skull to the other through the brain. They are nearly always immediately fatal but occasionally the patient survives and enters the hospital in fair condition. Very little need be done to these wounds as a rule. The wound of entrance is small and should be debrided in the usual way to a limited extent unless x ray study displays undriven bone fragments that are fairly easily accessible. The wound of exit which is much larger than the wound of entrance should be debrided locally and any loose bone fragments present should be picked out. As in other contaminated



## *The Treatment of War Wounds of the Brain*

wounds, the local use of sulfanilamide or sulfathiazole powder is indicated. If the injury is seen in the early stages, and if the patient is to be kept under observation by the operator, the wound may be closed after débridement, to effect primary union.

*Wounds involving the air sinuses.* These are extremely serious wounds because, in addition to the compound fracture involving the brain, there is the open sinus, which cannot be closed and which affords a site of continuing infection for a long period. In wounds that have traversed the frontal sinus, the usual débridement of the brain should be performed, as in other types of penetrating wounds. Any general fragmentation of the sinus should be cleaned away as well as possible, such portion of the mucous membrane as has been obviously contaminated or is dirty being removed. If the wound is operated on within the first twelve hours from the time of injury, the dura should be closed, if possible, and the area should then be packed widely open, with gutta-percha tissue or rubber dam against the dura, and with gauze over this for packing. Another method is to close the scalp wound, leaving a drain down through the frontal sinus and coming out of the nose. If such a wound heals by primary union, much time is saved for the patient, but this procedure is far less safe than the open method.

The particular danger present with wounds involving the brain and air sinuses is a cerebrospinal-fluid leak. To prevent this complication, it is imperative, when possible, to close the dura after careful débridement of the brain. If such closure is not possible, a muscle implant may be used over the ethmoid cells when this area has been opened, or a vaseline gauze pack may be placed against the dura and uncovered brain when the wound has involved the frontal sinus. If the wound has been closed either by primary union or by packing off, and if a cerebro-fluid leak develops, the patient must be reoperated on, and the fistulous tract from which the leak is coming sought. This is most frequently just above the cribriform plate of the ethmoid, and this area should then be sealed off with a muscle graft.

Another occasional complication of wounds through the frontal or ethmoid sinuses is the development of an intracranial aerocele. This is caused by the introduction of air through some portion of the dural laceration, and the patient as a rule begins to notice some increasing headache after a sneezing or coughing spell. X-ray study reveals the collection of air in one or the other frontal lobe. This air usually means a fistulous tract between a frontal sinus or the ethmoid cells and the brain. It must be sought and covered with a muscle graft to keep the aerocele from connecting with the ventricle and thus to prevent the



development of a cerebrospinal fluid leak. In all these cases, the continued use of sulfanilamide by mouth is advisable to offset any possible infection.

### Postoperative Complications

Patients who have had serious gunshot or shell wounds of the brain and have been operated on should have their wounds looked at carefully every day for a period of ten days to two weeks or longer if possible. If obvious infection is developing, as shown by puffiness and reddening over the operated area, the wound should, of course, be reopened promptly and left widely open, gutta percha or some other rubberized type of tissue against the raw brain area being used. It may be wise in some cases to suck out further devitalized material from the superficial portions, at least of the track within the brain and to treat the track just as one would a brain abscess—that is, by open drainage and by some smooth form of tissue next to the raw brain surface. It is a serious matter when these wounds do not heal by primary union and have to be opened up secondarily in this way, but it is not by any means a hopeless matter, since many of them heal in time with careful treatment, frequently, even a herniation or fungus eventually granulates and recedes and the wound covers over with epithelium in the usual way. When a fungus develops from this source, or when the patient has been operated on late and it is necessary to leave the wound widely open from the start, the fungus should be covered with some smooth material, such as gutta percha, as stated before, and then surrounded by a doughnut of cotton over which the usual gauze dressing is placed. The doughnut is used to prevent pressure on the fungus, which can only do harm, since it is not possible to keep the fungus from protruding and indeed it is not advisable to try to do so since such protrusion represents an effort of the brain to get rid of pressure. To prevent too great herniation of brain in this way, it may be advisable to do daily lumbar punctures, to reduce the pressure to a certain degree.

Other acute postoperative complications include meningitis and diffuse encephalitis. These can be treated only by keeping the pressure down so far as possible, by frequent lumbar punctures and by the general use of the sulfonamides according to the type of organism involved.

Another immediate postoperative sequela, especially in patients who continue to be either drowsy or stuporous for a long time, is the collection of mucus in the air passages. This must be repeatedly cleaned out by suction because if there is not a free airway and if mucus gets down into the bronchial tree, there is every likelihood of an atelectasis or



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another pulmonary complication. It is imperative to have some form of suction apparatus immediately available on all wards where unconscious or semiconscious patients are situated, because the collection of mucus is a serious matter that must be attended to promptly and frequently.

With the late complications of head injury, such as brain abscess, post-traumatic convulsions, headaches, dizziness and neuroses, this discussion does not presume to deal.

### **Summary**

In the treatment of gunshot wounds of the brain, stress should be laid on such prophylactic measures as can be instituted, particularly the use of tetanus toxoid and of the sulfonamide drugs. The second important feature is the urgent necessity of getting patients quickly to a hospital where complete operative treatment can be carried out for wounds that require such treatment. In general, the earlier these wounds can be treated, the better will be the chance of preventing subsequent infection. Certainly, whenever possible, patients should have their complete operation within twelve hours from the time of injury. No avoidable delay for other purposes can offset the advantages of early operation. Finally, a careful, complete and painstaking débridement of the wound, both of the skull and of the brain, should be carried out, preferably by those who are well trained in this type of surgery.

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## BRAIN INJURY IN WAR

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Recently it has been proved experimentally by Denny Brown that a head injury, in order to produce unconsciousness, must cause an acceleration of movement of the brain, either positively or negatively, to the extent of at least 28 feet per second. Such shaking of the brain usually does not occur if the skull is penetrated by a metal fragment going at high speed. Therefore, a man injured in this manner, if unconscious immediately, has usually been made unconscious, not by the impact of the missile but by the missile having ploughed through such an extensive area of brain tissue as to make it extremely unlikely that he can be saved. On the other hand a nonpenetrating blow on the head will often produce immediate unconsciousness without necessarily having destroyed or perhaps even injured permanently any brain area. In fact, I have seen an officer suddenly go blind during the last war, who denied to me that he had been hit. All he knew was that daylight had been replaced by complete blackness. When I found the pupils fixed, I knew his blindness was organic, but I failed, in the trench, to find any sign of a wound on the scalp. Later, at the casualty clearing station, a tiny, crescent shaped, red hairline was found above the hairline on the temple and x ray examination revealed a minute sliver of steel placed squarely in the optic chiasm.



or sulfapyridine; debridement should be effected as well as possible. (5) Antitetanic serum should be given. (6) Treatment for shock should be instituted immediately and operation ought to be delayed for twenty-four to thirty-six hours. Patients should be sent back to where x-ray facilities are available and then operated upon. Such a "head station" should be as near the front area as is militarily possible.

If the injury is treated early, the wound promptly filled with sulfanilamide and if it is not too large, the patient will probably survive.

It is now possible to treat such patients with a closed operation, the scalp being undercut and closed with interrupted sutures. For hemorrhages from dural vessels mosquito clips are best; avoid the cautery for these. The dura should be closed with a periosteal patch, especially if paranasal sinuses are involved. Suck out the blood clot in the track of the missile and irrigate with warm saline. Exploration is best carried out, not with the finger, but by means of a rubber catheter as Cushing taught us. Any wound big enough to be explored with the finger is hardly worth exploring. Finally, the track should be filled with sulfanilamide powder before closure. Do not be too squeamish about leaving inaccessible bone or metal fragments. One may do more harm by taking fragments out than the enemy did by putting them in.

After this procedure, sulfanilamide drugs should be continued. Luminal therapy should be started at once and an instruction tagged on the patient that luminal should be continued for a year more, because of the possibility of convulsions appearing within twelve or fifteen months.

If the wound has to be reopened for drainage, gauze impregnated with sulfanilamide or sulfapyridine should be used. On the whole, in these cases sulfapyridine is to be preferred to sulfanilamide as it has proved to be less depressing to the brain cortex.

If by the mischance of war or poor management the wound has not been treated in the manner described within forty-eight hours, it must be treated as an infection, that is, an open wound, as was habitual in the last war.

Since the effect of rapid closure is to produce increased pressure and acute cerebral edema, one must be prepared to deal with these by dehydration measures, including 50 per cent sucrose solution, caffeine, sodium benzoate, and if available, concentrated serum, given intravenously. This concentrate is prepared by adding 40 cc. of sterile distilled water to the dry solids obtained from 200 cc. of human serum, shaking well and incubating for one hour at blood temperature. Serum obtained from pooled blood requires no blood grouping. It is recorded



that in one case pressure fell from 275 to 80 mm within twenty minutes after the use of concentrated blood serum, rising later to a normal level of 110

Although in the last war the mortality rate after brain injury was said to be 60 per cent, I myself thought it was more. I saw somewhere that Cushing by means of his technic had lowered it to 28 per cent, but this was probably only on his own cases

I remember, just after the battle of Messines Ridge, I met Sir Anthony Bowlby on a road near where Cushing had been provided with a head hospital. I asked General Bowlby how Colonel Cushing was doing, and he replied enthusiastically, 'He is doing beautiful work, but he has only done 8 cases in a day. We shall have to ring the Germans on the telephone and ask them to call off the war to give Cushing time to catch up!' We must remember always, in making our plans, that there is a war on. One must work fast when convoys of wounded are pouring in, perhaps under fire, and orders to evacuate may come in the middle of an operation, so one must be swift to change methods.

In basal fractures, it is well to remember that the dura is firmly attached to the basal portion of the skull and, therefore, is nearly always torn. There is danger in these cases of the fracture being compounded into the nose, ear or accessory sinuses, with subsequent risk of infectious meningitis. If an x ray can be taken and discloses intracranial air, the compound nature of the injury is proved. I once saw a lady in Paris who fainted suddenly, falling forward on her forehead. She was immediately unconscious. When an x ray was taken a perfect ventriculogram was found, a fracture of the posterior wall of a frontal sinus had allowed air to whistle into the cranial cavity, fill the ventricles to distention, so that at the American Hospital she was accused of amnesia for a recent lumbar puncture with air injection.

All cases of stiff neck do not necessarily signify infectious meningitis since this may be produced through seepage by gravity of subarachnoid blood. If one has the chance of doing a lumbar puncture to establish the presence of blood in the spinal fluid, this should be done, except in those cases in which leakage of spinal fluid from the nose, ear or sinuses or bleeding from the ear or nose have demonstrated the presence of basilar fracture.

The tomograph, an instrument by which roentgenologists can visualize and localize structures and foreign bodies in three dimensions, should be part of the equipment of every base hospital. The use of electric magnets for the extraction of fragments was common in the last war, and I understand is still being used but this is a base hospital operation.



and has its limitations.

The following are a few suggestions: (1) The bladder of any unconscious patient should be closely watched. (2) Sulphur containing drugs, like epsom salts should not be used if sulfanilamides have recently been given. (3) Where flying ambulances are used, patients who are receiving sulfanilamides or related drugs, should not be transported at high altitudes, lest sudden death occur from lack of oxygen. (4) Patients with compound fractures into the nose must be instructed not to blow the nose. (5) When burns occur, hydrosulfosol may be used as a spray; diluted 1:20 it may even be used for the eyes.

At the beginning of this discussion, I tried to outline a procedure for penetrating head injuries. I should like, in conclusion, to add a similar outline for the care of nonpenetrating head injury: (1) Treatment of shock by the intravenous injection of 100 cc. of 50 per cent hypertonic glucose solution or blood serum as already described; (2) lumbar puncture for diagnosis and treatment; (3) repetition of hypertonic dextrose by vein to reduce increased intracranial pressure (100 cc. of 50 per cent solution, three times daily); (4) injection of caffeine sodiobenzoate,  $7\frac{1}{2}$  gr. (0.5 Gm.) every four hours (hypodermically); (5) rectal taps of 25 per cent solution of dextrose, 4 ounces (120 cc.) every four hours; (6) elevation of head of bed 15 to 45 degrees; (7) the carrying out of operative procedures in cases suspected of progressive middle meningeal hemorrhage; (8) the use of antimeningococcic serum in suitable cases and antitetanic serum in all patients with a scratch on them; (9) the performance of right subtemporal decompressions in comatose patients with marked papilledema, who do not respond to the aforementioned procedures within three days; and (10) uncomplicated depressed skull fractures may be elevated after the acute stage of shock has passed. Surgical interference in this group may often be safely postponed for many days.



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the cranial mass by means of the orbital processes of the frontal bone. A blow on the external wall of the orbit meets stout resistance as the retrocussions are transmitted from the malar bone to the frontal and superior maxillary, while the zygomatic arch resists the shock by transmitting the force of the blow to the temporal bone.

The wall of the orbital cavity is also extremely resistant to external trauma, being solid below and well protected on the outside by the normal musculature of the face. It is thin above and fragile within, but here, again, nature has provided an excellent shock absorber to any blow having sufficient force to cause a fracture; namely, the concavity formed by the sphenoidal and sphe-no-maxillary fissures. The internal wall is protected by its fellow of the opposite side. Because of the thinness of the superior wall and its continuation as orbital wall it is most often injured.

The vulnerability of the orbit is due to its important orifices. Let us first consider the base. While at first this may seem an easy entrance for any foreign body, this open space is rapidly decreased by a slight tilting of the head, up or down or from side to side. It is certainly reasonable to suppose that any individual sensing danger will not assume a perfectly erect position. The other avenues of exit are the optic foramen, the sphenoidal fissure, and the pterygo-maxillary fossa. But the internal wall covering the ethmoids can hardly be considered a barrier; it is not a direct communication, but its resisting power is practically nil, so that sanguinary effusions easily find their way from the optic foramen, sphenoidal fissure, and ethmoids, producing orbital hematomata and exophthalmias.

The pterygo-maxillary fossa is relatively a ready means of communication between the contents of the orbit and the retromaxillary and jugular regions. According to Pascal's hydrostatic law and in the opinion of Dr. Felix Lagrange, which my own slight experience confirms, a missile penetrating into both the facial bony mass and soft parts will produce vibrations that are transmitted to the orbit by the pterygo-maxillary fissure, and a commotion in the orbit is produced. First the eye is proptosed, the optic nerve acting like a rubber band, and if the force of the missile is great a rupture of the posterior part of the globe may take place or an avulsion of the nerve. What applies to this region can also affect important structures in the retromaxillary and jugular regions.

In order to understand the clinical pictures produced by wounds of the orbit we must recall to our minds the strictures that enter it, and in war wounds we find many interesting puzzles. A sort of com-



posite picture resolving itself into various injuries of brain, bone, nerve, and blood vessels is produced, and there are often added symptoms of many degrees and all kinds of infections. They are fantastic lesions comparable to a cross word puzzle whose solution can be solved only by a thorough knowledge of the anatomy of the orbit.

Surrounding the orbit are three important foramina, namely, the supraorbital, infraorbital, and foramen for the malar nerve. Within the orbit are the optic foramen, the sphenoidal fissure, and communication with the pterygo maxillary fossa. If we reflect upon the important structures that go through these foramina and understand their function the complex puzzle is solved. However, consideration of the minute anatomy, cannot be entered into in a treatise of this kind.

As to missiles in general, the machine gun bullet very seldom is found in the skull. It usually kills the individual at once, or, passing entirely through the structure, leads to one of those indelible pictures which I have previously mentioned. The most frequent foreign body met with in the head, in my experience, is the irregular shell fragment. Because of its jagged contour this fragment of the high explosive shell meets considerable resistance and produces terrible deformities. The missile next most frequently encountered and likely to remain in the skull is the shrapnel ball. From an entirely military point of view this means of destruction seems to me to be obsolete. I would venture to predict that fragments of the high explosive shell, machine gun bullets, and the effects of gas will be the concern of the future surgeons in war. The entrance and exit of the bullet are of interest. At the wound of entrance in the skull we usually find an exostosis, while the spent bullet produces at the aperture of exit a depressed excavation of the underlying tissues for it usually takes with it some of the bony structure upon exit. In other words, there is produced a knifelike entrance, but on exit because of malposition or malformation, the bullet becomes similar to a shell fragment, causing a wound of exit that simulates the entrance wound of a high explosive shell. Of course if the bullet is travelling with high velocity and is fired at close range a clean through and through wound is usually produced.

Dr Felix Lagrange from his vast experience has corrected and correlated many ophthalmic lesions that are of interest to the Army surgeons. He found that certain fundus lesions are produced by concussion and states that there is a distinct relationship between ocular lesions and disorders produced by foreign bodies in the facial bony structures. In other words "the same disorders of bones correspond always to identical lesions in the eye." As a consequence he formulated certain laws, based



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on clinical evidence, to which the interested reader would do well to refer.<sup>1 2</sup> Briefly they are as follows:

(1) The concussion of air by an explosion can cause lacerations of the uveal tract, especially at the posterior pole. Luxation, subluxation of the lens, and traumatic cataract are definite and well-known pathologic entities of this injury.

(2) When the missile passes above the orbit, injuring the frontal bone and the anterior cerebral region, it produces fractures of the orbital vault at the level of the optic foramen and sphenoidal fissure, causing disorders in the sensory, motor, and optic nerves without injury to the eyeball.

(3) When the missile travels through the face below the eyeball, without going through the orbit and without fracturing it, it produces lesions by concussion, affecting the eye in the region of the macula. This is the most frequent cause of loss of acuity of central vision.

(4) When the missile has fractured the orbit, partially crushing in the wall without injuring the eyeball, there are produced in the eyeball serious concussion injuries, macular lesions, and choroidal ruptures. Macular lesions occur irrespective of the wall damaged. There also exist peripheral lesions always seated in front of the orbital wall that has been injured by the missile. Probably the orbital wall is fractured, at the same time, raised, and thrust on the eyeball, producing a lesion by contact; but whether the contact exists or not we have always observed that the peripheral lesion of the inner membranes is always situated in front of the fracture.

(5) When the projectile passes through the orbit, the eyeball not being involved, the same disorders are produced together with those which result from the lacerations of the organs contained in the orbital cavity; the optic nerve is often severed; and the papilla is lacerated as if torn away (avulsion of the optic nerve).

(6) When the missile grazes the eyeball tangentially without rupturing it, or when the globe is contused by the orbital wall being driven in upon it, there arise immediate disorders in front of the contused spot (choroido-retinal lacerations with retinal detachment and proliferating retinitis); the macular region is often involved in the damage but it is not injured alone.

In discussing the first group of cases Lagrange points out that the lesions are induced by a column of air agitating the ocular wall, producing lesions at the posterior pole. He states that lesions by concussion are situated in the uveal tract, and that in any violent concussion of the eyeball this tract gives way first, inducing a choroidal rupture or concussion lesion. A rupture of both the choroid and retina (this is important) produces lesions by contact, and in the end a traumatic proliferating choroidoretinitis, not a retinovitreal proliferation. We have seen a number of such cases of contact injury. I have very vivid recollections of two concussion lesions. After the Armistice it was the custom of the men to sneak out over the "playgrounds" and bring back various souvenirs to Paris. Once, while unloading a shell, it exploded, killing a number and sending four or five wounded to our hospital. Two of the men, while wounded in the chest, had no wounds of the face; yet



there were typical concussion choroidal lesions at the macula, the lens showing no evidence of injury

The visual disturbances in the second group of cases are self explanatory, but in most of our cases optic atrophy was often associated with other nerve lesions

In the third category the lesions are injuries received by a missile at a distance, producing macular lesions due to the transmission of vibratory concussions to the orbit through the medium of the pterygo maxillar fossa and fissure. The situation of these lesions at the posterior pole is due to the delicate structure of the macula and the attachment of the optic nerve

The fourth group of facts needs little explanation. We have a macular lesion and a choroidal and retinal lesion in front of the fractured orbital wall. We observed in these cases of choroidal and retinal rupture the typical picture of a traumatic proliferating choroidoretinitis

In the fifth group of facts, in addition to the lacerations of the organs in the orbital cavity there is often to be found the classical picture of partial or total avulsion of the optic nerve that I shall discuss in detail later

In the sixth group of facts we find lesions produced by bullets that are represented by ruptures of the choroid and retina caused by a missile grazing the eyeball without rupturing it, inducing from the contused spot in the eyeball lacerations especially toward the posterior pole. In this class of cases we have a typical picture of traumatic proliferating choroidoretinitis, the end result of a double laceration of the choroid and retina

If we compare tumors to shell fragments and in a way consider infective processes or toxic disturbances somewhat similar to hemorrhagic processes produced by missiles, we believe that neurologists and brain surgeons will readily realize that the lesions of war injuries and peace time pathologic processes are somewhat akin. In our experience there is decidedly a more rapid clearing of intraocular hemorrhages due to injuries than in those of nontraumatic origin. We have also seen some detachments of the retina caused by trauma reattach by merely rest in bed, as the classical operations for detachment were not in vogue at the time of the first World War

In civilian ophthalmic practice we are not inclined to be so fastidious in regard to the neurologic examination around the orbit, but in military ophthalmic examination, all injuries of the eyeball should be considered as coincident to orbital injuries, and these in the great majority of cases leave definite neurologic lesions such as anesthesia, hyperesthesia, and



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muscle spasm, their location being determined by the pathology produced in the structures involved.

In any injury of the eye or orbit I would suggest the following routine method of examination.

1. (a) Examination of skin around the orbit for areas of anesthesia or hyperesthesia. (b) Look for spasm or paralysis of facial or ocular muscles.
2. (a) Palpation. Determine if there is cerebral pulsation; (b) loss of bone substance; (c) exostosis.
3. (a) See if there exists exophthalmos or anophthalmos; (b) bruit.
4. (a) External examination of the lids and lacrimal sac. (b) Examination of orbital margin for malformations or loss of tissue. Inspection for infected sinus (other than those coming from the ordinary sinus of the skull).
5. Examination of media, cornea (sensitivity), lens, vitreous, and fundi.
6. Determination of vision; charting of fields; mapping out blind spot; charting scotomas; testing color vision.
7. Testing the muscle balance.
8. Auscultation. (a) Bruit. (b) Vocal resonance. Compare the sound of the spoken voice of the patient when a stethoscope is placed directly over the closed eyeball of the injured eye with that of the uninjured eye with a stethoscope similarly placed. In our experience sometimes orbital complications such as the presence of a missile may increase the vocal resonance when tested in this manner.
9. Nasal examination; careful examination especially for intra-nasal adhesions.
10. Mouth and oral examinations.
11. X-ray. Determine the exact location of the foreign body. When this refinement is not at hand we have to resort to
12. Probing. This procedure to my mind is very important, and eliminates in a great majority of cases the necessity of a Kronlein operation for the removal of shell fragments.
13. Complete neurologic examination and fluoroscopy of the entire body.

Five unusual conditions are found in war surgery that are comparatively rare in civilian practice: 1. Traumatic proliferating choroidoretinitis of Lagrange. 2. Spastic entropion (blepharospasm). 3. Avulsion of the optic nerve. 4. Enophthalmos (true and false). 5. Hematic pigment ring of the disc.



**Traumatic Proliferating Choroidoretinitis of Lagrange**

This condition is produced by a missile striking the wall of the orbit fracturing it or by its striking a glancing blow of the eyeball without rupturing it. Such an injury produces waves of force that are transmitted through the orbital fat, resulting in a concussion of the eyeball. Secondly, there is produced a rupture of the uveal tract resulting in hemorrhages involving the choroid, retina, and possibly the retinovitreal spaces. The site of the lesion is not retinovitreal, as so often occurs in young individuals with recurring hemorrhages. The terminal picture is a connective tissue proliferation with the formation of fibrous tracts, the choroid being the productive factor in this unique lesion.

**Spastic Entropion Blepharospasm**

This condition often comes on after postoperative convalescence and is induced by irritation or traumatism to the infraorbital nerve. It is usually caused by a foreign body situated behind the eyeball near the apex of the orbit. Sir Herbert Parsons has advocated, and reported successes by, resecting the nerve in the orbit. The following operation was performed by me in France for a spastic entropion of the lower lid and I have used it subsequently in ordinary routine practice with excellent results.

*Operation for spastic entropion of lower lid.* The eyeball is anesthetized and the hard rubber plate, lubricated with sterile vaseline, is introduced under the lower lid. The ordinary injection of novocaine infiltration is used, for this gives more bulk to the muscle and makes the dissection easier and more accurate (fig 1 A). Next an incision is made in the skin of the lid, 4 mm from the lid margin, and the length of the palpebral fissure. The second somewhat crescent shaped incision joins the first, the largest width of the crescent being 3 mm (fig 1 B). The skin is dissected free and the exposed fibers of the orbicularis are shown (fig 1 C). This drawing depicts the muscle that is to be dissected. Figure 1 D shows the method of dissection. Figure 1 E illustrates the manner in which the sutures are introduced. They are first placed in the skin of the upper incision and then in a horizontal direction in the tarso orbital fascia grasping, if possible, some of the tarsus. This bite should bisect the entrance and exit of the suture. Figure 1 F shows the wound closure.



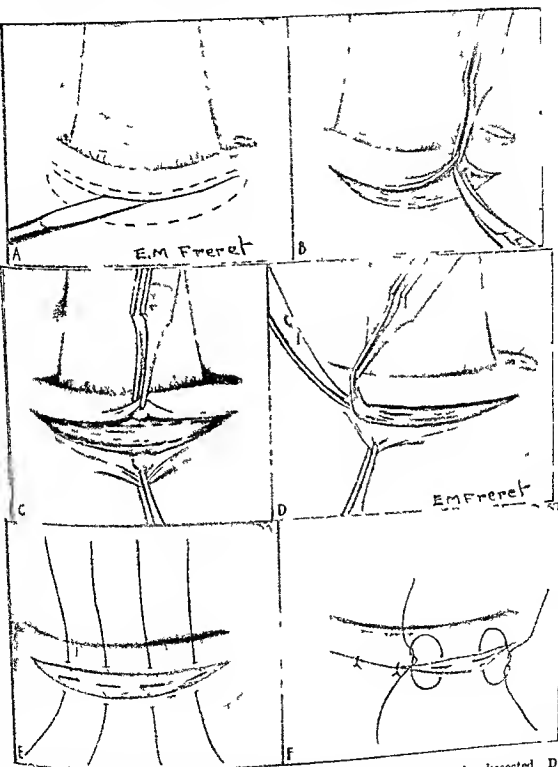


Fig 1 (Doherty) A and B incision, C, demonstrating the muscle to be dissected D, excision of the orbicularis, E, method of introducing sutures F, closure of wound



### **Avulsion of the Nerve**

This ophthalmoscopic picture is rare in civilian practice but occurs in the majority of cases of suicide. During my service I saw a complete avulsion of the optic nerve in both eyes caused by a machine gun bullet, and I am positive the patient did not die of this injury. In an injury that produces an avulsion of the optic nerve there is a profuse hemorrhage which rapidly absorbs. The disc appears white and blurred, often excavated and is usually surrounded by the characteristic traumatic proliferating choroidoretinitis or fibrous plaque. This may completely or partially fill the excavation. In the latter case we are in all probability dealing with an incomplete avulsion of the nerve. The picture somewhat simulates a congenital coloboma of the disc but in avulsion of the nerve the blood vessels are characteristic appearing often completely devoid of blood and resembling long white cords. The fibrous plaque is also distinctive of this condition. In my cases it had a dull white appearance with a seagreen sheen which in all probability was due to the blood pigment. As the condition progresses the plaque becomes a dull white. This mass lies in a simple relation of proximity with the vitreous body. It projects only moderately usually en masse and is totally unlike the ordinary retinitis proliferans due to organization of effused blood whose membrane is translucent the projections ending free in the vitreous. In traumatic proliferating choroidoretinitis secondary retinal detachment does not occur and in fact produces adhesions that very closely cement the choroid and retina.

### **Enophthalmos, True and False**

True enophthalmos should be designated as a retraction of the globe due to injuries sustained by trophic disturbances.

False enophthalmos depends upon a depression of one of the walls of the orbit producing an enlargement of the orbital cavity and a secondary pushing in of the eyeball. In the early days of injury the eyeball may have a rather marked exophthalmos due to retrobulbar hemorrhage but after a few weeks the patient usually complains of ptosis false ptosis due to faulty support of the upper lid by the eyeball and limitation in the ocular movements.

### **Hematic Pigment Ring of Disc**

These are produced by hematomata of the sheaths of the optic nerve and the ring is created as an end result by the slow migration of the hematic pigment. The first symptom is usually a semiannular para-



*Some of the Most Important Ocular and Orbital Wounds in War*

central scotoma, which is followed by a blackish red pigmentation around the scleral ring. Both scotoma and pigment ring sometimes have a tendency to clear up.

A few of the interesting cases that we have encountered are reported herewith.

Case 1. Figure 2. The following autopsy report needs very little explanation Only relative data are given:



Left Right  
Fig. 2 (Doherty). Case 1. Piece of high explosive shell can be made out and wire uniting fragments Area of bone loss can also be seen.

Autopsy No. 126. American Expeditionary Force.  
American Red Cross Military Hospital No. 2 Col. Joseph Blake, Command-  
ing.

Name: L——, P.G

Organization: F Co, 30th Engineers

Date of death: 19 Dec. 1918, 3 p.m.

Date of autopsy: 19 Dec. 1918, 4 p.m.

Pathologist: 1st Lieut. H. W. Hundling, M.C.

Rank: Private

Age: 21 Race: White

Place of death: A.R.C.M.H. No. 2

Place of autopsy: -do-



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anterior and posterior ethmoids after the alae nasi had been reflected by an incision along the nasal cheek groove. This operation gives a beautiful view of the interior of the nose and was practiced on difficult submucous resections in the clinics of Paris during the first World War. With careful suturing there is practically no deformity of the alae.

*Case 2* Figures 3, 4, and 5. While this was not a case of war injury I feel justified in reporting it. The patient J. M., was wounded with a shotgun in October, 1926. He was first examined by me one



Fig 3 (Doherty) Case 2, front view  
From the New York Eye and Ear Infirmary

year later. The eye was quiet, there was a traumatic cataract, and the light projection was faulty. He had been told there was no foreign body in his eye but that the optic nerve was injured. A careful localization by Dr. George S. Dixon of the New York Eye and Ear Infirmary proved this to be false (see fig 5). The following X-ray report was returned: One hundred and twenty-nine bird shot were counted in the right side of his head, face, and neck, but only one shot and one fragment were located in the globe of the right eye, numbers 1 and 2. Numbers 3 and 4 are in the orbit. The patient refused any operative interference at this time. Four years after his original injury the right eye became red and painful, and he again consulted me. Examination showed a large hemorrhage in the anterior chamber, an iris bombe



attached to the anterior capsule of the lens, the lens to be cataractous and the eye soft and shrinking. The X ray examination confirmed the



Fig 4 (Doherty) X ray, lateral view, case 2 From the New York Eye and Ear Infirmary

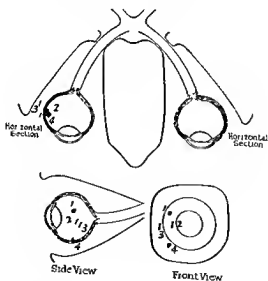


Fig 5 (Doherty) Case 2 X-ray charting of foreign bodies From the New York Eye and Ear Infirmary One hundred twenty nine shot counted in right side of head face, and neck Two foreign bodies in globe and two in orbit of right eye





Fig 6 (Doherty) Case 3 A, X ray, lateral view showing foreign body (bullet), B front view C, remnant of bone found in eyeball From the New York Eye and Ear Infirmary

existence of the foreign bodies and because of the danger of sympathetic ophthalmia the eye was enucleated This case certainly stresses the need of careful localization in injured eyes when there is a suspicion of an intraocular foreign body

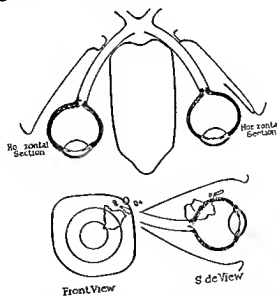


Fig 7 (Doherty) Case 3 X ray chart showing of foreign bodies One large and six small pieces located in a square 12.5 by 17.6 mm From the New York Eye and Ear Infirmary



*Case 3* Figures 6 and 7 In 1921 the patient, J L, while engaged as an agent of the Federal Government was shot from ambush The bullet entered the skull just above the orbital ridge of the frontal bone on the left side He was taken to the home of a physician who rendered first aid and was later removed to New York The X ray examination showed the bullet to have flattened in the orbit apparently without rupturing the eyeball Four years later (1928) he consulted me Examination disclosed a convergent strabismus with a traumatic cataract The pupil reacted to light the light projection was faulty, but the tension of the eye was normal The patient complained of pain in the orbit so I removed the largest piece of the bullet but was unable to



Fig 8 (Doherty) Case 4 X ray showing machine gun bullet in orbit Lateral view

find the smaller fragments For cosmetic reasons an operation for squint was performed with an excellent result One year after the operation I was again consulted This time the eyeball presented marked evidence of iridocyclitis the tension was minus and I advised an enucleation Following the removal of the eye a very extraordinary situation was found A remnant of the bony part of the orbit was located inside the eyeball (fig 6) The presence of this intraocular bony foreign body was not revealed by the X ray but must have existed from the time of the accident it could not be confused with the ossification of the choroid as is clearly indicated in the illustration

*Case 4* Figure 8 The patient was wounded during the Chateau Thierry drive There was a jagged perforation of the lower lid but



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the eyeball certainly gave no indication of what had happened. Examination showed a slight exophthalmos with a marked ecchymosis of both upper and lower lids. There was a jagged perforation of the lower lid with some loss of tissue. On separating the lids the cornea appeared normal, and the anterior chamber was completely obliterated by the hyphema, the tension of the eyeball was minus, and there was no perception of light. The X ray disclosed a machine gun bullet which, ricocheting from the front, struck the lower rim of the orbit, producing a fracture, and penetrated the posterior part of the globe where it remained embedded about half in the globe and half in the orbit. Needless to say the eye was enucleated and the machine gun bullet extracted. This was one of the many freak cases that I encountered.



Fig 9 (Doherty) Case 5 X ray showing piece of high explosive shell in apex of orbit

*Case 5* Figure 9 This case presented a partial avulsion of the optic nerve with ophthalmoplegia externa, later followed by neuroparalytic keratitis. The pathology was caused by a piece of high explosive shell which entered just behind the superior external angle of the orbital opening. It literally plugged the apex of the orbit. With a probe the tract of the missile could be traced. The foreign body was extracted.

*Case 6* Figure 10 The missile in this case entered the skull just below the eyelid, producing a fracture of the left inferior external orbital wall. It penetrated the orbit from below upward and was removed in the region of the lacrimal gland. The fundus presented macular and peripapillary choroidoretinitis (concussion lesions).



*Case 7* Figure 11 A small particle of high explosive shell produced a fracture of the frontal sinus on the right side. It passed along the internal wall of the right orbit, traversed the superior maxilla and roof of the mouth and finally lodged in a lateral part of the neck. Vision was 20/20 and there were no fundus lesions. Needless to say the shell splinter was not removed and my first record showed a discharging fistula from the frontal sinus.



Fig 10 (Doherty) Case 6 X ray showing position of piece of high-explosive shell

*Case 8* In 1918 the patient F. D. was plowing on one of the battle fields in Italy when his plow struck a shell causing it to explode. He felt a stinging sensation in his right eye but the only treatment he gave the eye was to bathe it in boric acid solution. The eye remained red for a few weeks and then seemed to quiet down. During the 13 years following the accident he had a number of attacks of redness, pain, lacrimation and photophobia lasting from four days to several weeks but received very little medical attention. He came to the New York Eye and Ear Infirmary for an examination because of a diminution of vision in the right eye and wished to learn if glasses would improve his vision which was reduced to 20/200. This reduction of vision was due to organized exudate on the anterior capsule of the lens secondary to previous attacks of iritis. A careful examination of the iris with a slit lamp revealed a small nodule tubercular in appearance situated in the iris at the 7 o'clock position. There was no evidence of siderosis but because of the history of an accident an X ray examination was



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made, which showed the nodule to be a small encapsulated foreign body. It was not magnetic, so the anterior chamber of the eye was opened with a keratome, the nodule grasped with iris forceps, and removed through a small iridectomy opening.

This case emphasizes the fact that many of the so called red or inflamed eyes that have been treated for various types of inflammation sometimes prove to contain foreign material that has existed for years,



Fig 11 (Doherty) Case 7 X ray showing small particle of high explosive shell lodged in lateral part of neck

its presence finally detected only by special technique with careful X ray examination

Much discussion has been devoted to the question of the tolerance of the eye to various kinds of intraocular foreign material. The preservation of a useful eyeball under such conditions does not depend upon the actual invasion of microorganisms but upon both chemical decomposition of the substance and mechanical irritation. All aseptic foreign bodies after a time decompose or become encapsulated and their presence within an eye will ultimately lead to its destruction or produce a marked loss of visual acuity. Certain tissues of the eye will react differently to



foreign bodies. The iris and ciliary body usually react more seriously to injury than does the lens or vitreous and certain substances seem to be more of an irritant than others. Copper usually induces violent inflammatory reactions; iron if not encapsulated forms an oxide that causes a discoloration. Wood lead or other foreign material that is not magnetic is always of a more serious character because the extraction of such substances obviously involves more trauma and manipulation than does a magnetic foreign body that can be extracted by means of an electromagnet.

The appearance of an injured eye gives no clue as to the absence or presence of a foreign body; it is only by careful examination by means of the X ray that we can make a positive diagnosis. A positive diagnosis of a foreign body by means of the X ray is not sufficient, an accurate plotting to determine the size and position of the missile must be made in order to insure a successful attempt at its removal.

In general we find concussion lesions in or around the macula manifested by hemorrhages, lacerations of the choroid and also choroido-retinal ruptures. A concussion in contact lesion may coexist. The following case is illustrative of such an occurrence.

*Case 9* Figure 12 R G male aged 19 years stated that on September 15, 1941 while using a mop wringer the spring flew from the bucket and struck him in the left eye. Examination showed a very small superficial wound of the skin of the lower lid. There were no other signs of injury to the lids, conjunctiva, cornea or iris. The iris was partially dilated but did react sluggishly to light. The lens was clear. The vitreous showed no pathologic involvement.

The fundus which could be plainly seen presented a rather unusual classical picture. There was an intense edema with a marked cherry red spot (fig 12 A). The disc presented no abnormality nor were there any vascular changes. In the periphery below appeared what could be described as a blood blister. The upper part of the blister contained what resembled a yellowish fluid. This is the typical early picture of traumatic proliferating chorioretinitis (contact lesion) due to ocular concussion by contact inducing secondarily a rupture of the uveal tract and retina. In the macula there was a typical early concussion lesion. Figure 12 B shows the same condition 11 days after the injury. The rapid organization of the extravasated blood in the contact lesion below with the ultimate formation of a dense fibrous plaque is readily observable. The edema in the macula has cleared and this area now presents a hole in the macula toward the nasal side of the choroidal rupture. There is a central absolute scotoma.



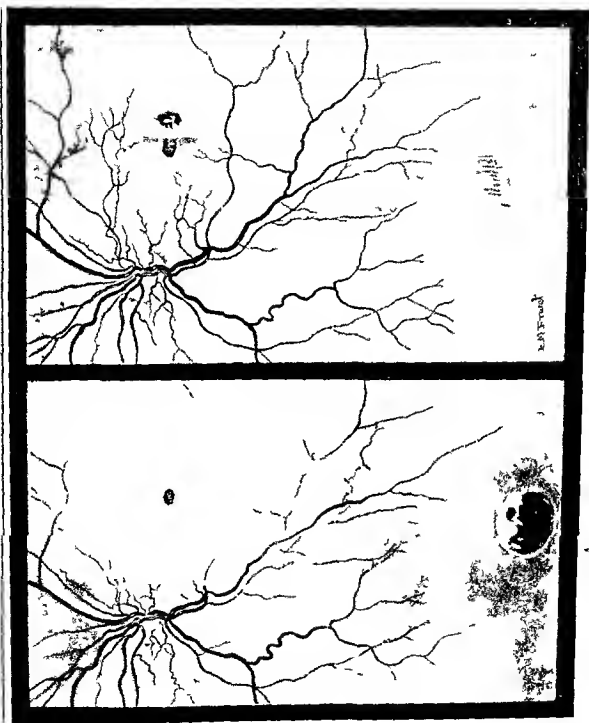


Fig 12 (Doherty) A fundus as it appeared 24 hours after the accident B the fundus 11 days after the primary injury



An interesting observation made by Lagrange is that fractures of the cranium by projectiles of war, implicating the cranial vault, at a distance from the orbit even when they are accompanied by large losses of substance and in consequence by well marked concussion, do not give rise to fracture by contre coup of the vault of the orbit. Contrary to what is taught in the classical literature the sphenoidal fissure, the optic foramen and the structures that pass through them remain unharmed after such traumatism. In military surgery fractures of the orbital vault are direct fractures.



Fig 13 (Doherty) Types of orbital fractures

In wounds of the orbit (fig 13) certain procedures should be carried out. Any immediate wound of the orbit or surrounding structures usually produces marked swelling, ecchymosis, and profuse intraorbital hemorrhage so that secondarily there is often found a very marked exophthalmos. In the first aid station after the ordinary attentions of asepsis are carried out—that is flushing the wounds with hydrogen peroxide, applications of tincture of iodine and the injection of anti-tetanic serum—the attention of the surgeon naturally turns to the eye. I used the word *surgeon* because an ophthalmologist in a first aid station is out of place. Many sad recollections come to my mind pointing to the fact that if a few important fundamentals had been made known to the general surgeon many deformities of the lids and orbit would have been greatly lessened and many eyes saved by the best possible first aid treatment under exceedingly trying conditions.

In marked cases of exophthalmos in order to protect the cornea, bichloride ointment 1:3000 should be instilled in the cul de sac, then the lids should be sutured together in the quickest and easiest way placing the sutures so that they are not directly over the cornea and



applying an appropriate dressing. At the front speed is very necessary, and no surgeon can or should try to produce the classical picture seen in the well-equipped hospital. In fact no restorative work of any kind should be attempted until two to four weeks have elapsed. This statement also applies in the removal of bullets. A surgeon in the first-aid station should be warned against probing for bullets. He should be cautioned against removing any tissue and above all he should never remove any fragments of bone found around the orbital margin. His work after rendering first aid should consist of placing the mutilated parts back in as good position as possible and then put on a snug supporting dressing for transportation to the rear. Even if the globe is hopelessly injured any eyeball can be more skillfully enucleated after the ecchymosis and swelling have subsided, and I believe there is very little danger of sympathetic ophthalmia in allowing any mutilated eyeball to remain in the socket for two weeks.

In briefly discussing reparative surgery due to loss of substance of the orbital margins, three materials have been successfully used. First, cartilaginous grafts; second, adipose grafts; third, metallic plates. Cartilaginous grafts, so far, have proved their worth, and many operators have reported brilliant results. Adipose grafts have also been successfully used, especially in filling up marked depressions. There is now, however, an alloy, vitallium, that is beginning to be extensively used by plastic surgeons for restorations. In my opinion, because vitallium lies inert in the body tissue, molds of this alloy would give beautiful results in this particular type of work. I am inclined to believe that this cobalt chromium alloy has been somewhat overlooked by the plastic surgeons and has not been given the place it properly deserves in this very specialized branch of surgery.

Cases and photographs were obtained while in the service in the A.E.F. as Captain in the Medical Corps, United States Army; attending ophthalmologist at Colonel Blake's Hospital, Paris, France.

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# OPHTHALMIC CASUALTIES RESULTING FROM AIR RAIDS

By DOROTHY R CAMPBELL, M A, M.B, B S

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We are now becoming familiar with the types of ocular injury which result from air raids. They usually occur in conjunction with other injuries and are regarded as of secondary importance, particularly during the first few days of treatment.

## Types of Injury

There appear to be three main causes of ocular injury (1) explosive incendiary bombs, (2) the sudden compression and expansion of the atmosphere caused by blast, (3) direct blows on the eye.

The resulting injuries present certain features and problems of treatment which are new to the ophthalmic surgeon, and an outline of my observations on approximately 100 cases may therefore provide an interesting comparison for ophthalmic surgeons in other large cities. These notes were made after the raids in October and November, 1940, and have been modified by further experience.

## Effects of Incendiary Bombs

In a mild degree the effect of an incendiary bomb was that of multiple foreign bodies—particles of sand and oil were embedded in the eyelids, conjunctivae, and cornea. Whenever possible the foreign bodies were removed from the cornea immediately, flaine oil and atropine was instilled, and when only one eye was affected the patient was able to return home. The eye usually became quiet in one or two weeks.

There were, however, many cases in which the eyes had been burned, and usually both eyes were affected. The lids and conjunctivae swelled and the corneal epithelium was too oedematous to admit of removal of the foreign bodies for perhaps a week. The patients suffered severe pain and had to be removed to a base hospital, where they made a slow recovery. It was found by experience that metycain and merthiolate ointment gave great relief in the initial stages, without any ill effects on the cornea. Atropine was also administered and, later, saline lotion and collosol argenti drops were employed. It was found better to remove the foreign bodies a few at a time. In one case in which a large number were removed from both corneae a week after injury an alarming infection followed within forty eight hours. There was a general rise in



### *Ophthalmic Casualties Resulting from Air Raids*

temperature, and a corneal abscess and hypopyon developed in both eyes. Large doses of sulphapyridine were given, followed by graduated intravenous injections of protein-shock T.A.B. Both eyes were retained; one had 6/12 vision, but in the other there was a perforated cornea.

I was impressed by the softening of all the ocular tissues. In addition to the softening of the cornea I noticed a persistent oedema of the conjunctiva; sutures put into flaps to cover a perforating injury very quickly cut out, and many cases showed lymphatic blebs in the conjunctiva which persisted for weeks after the injury. The sclera, too, appeared to be oedematous, for two cases in which deep burn penetrated to the sclera, developed a spontaneous rupture, and prolapse of the vitreous several days after injury. Secondary infection was rare, but in one case a most intractable attack of superficial punctate keratitis occurred. The resulting vision was usually good, except in the few cases with infection of the cornea, but the eyes remained irritable and injected for many weeks, and there was permanent staining of the conjunctivae.

In addition to the injuries already described, incendiary bombs often caused burns of the eyelids and face which were usually superficial and which were best treated with sterile petroleum jelly. This facilitated the dressing of the eyes and retained the mobility of the lids.

In contrast to these, deep burns of the eyelids occurred in conjunction with extensive burns of the face in firemen and A.R.P. workers directly exposed to fire. The eyes themselves were usually uninjured, and this enabled the gentian violet-silver nitrate treatment to be used in the first instance, followed by petroleum jelly when the lower lids became softened by laceration. Contraction was very apt to occur, and necessitated stitching the eyelid margins. After three months two cases were treated successfully with Thiersch grafts.

#### **Effects of Blast**

Some peculiar effects on the eye of sudden compression and expansion of the atmosphere were noticed: (a) Proptosis due to a sudden retrobulbar haemorrhage causing immediate total loss of vision: the usual signs of evulsion of the nerve were absent, yet subsequent optic atrophy occurred. (b) Extensive intra-ocular haemorrhage either from an iridodialysis in which the iris vessels were torn through, or from a torn retinal vessel. (c) One or more ruptures of the choroid appearing as crescentic tears near the optic disks: these were quite different from the familiar contusion changes of the retina and were accompanied by small haemorrhages at the macula, with loss of central vision. (d) Acute iritis and acute secondary glaucoma occurred in several cases



about a week after injury. These were slow to recover. Investigations were made for any constitutional factor, but they appeared to be due entirely to trauma.

### **Effects of Direct Blows**

Perforating injuries of the cornea and rupture of the sclera from a direct blow were common injuries and usually the eye had to be removed. Several cases showed a severe traumatic keratitis with multiple folds in Descemet's membrane. Although the cornea cleared well there were always associated contusion changes in the retina, particularly at the macula, giving rise to defective vision. Several cases of penetrating wounds of the orbit occurred in which large particles of wood and glass were buried deep in the tissues, but the sinuses healed up well, as did wounds of the eyelids. There were no cases of intra ocular foreign bodies requiring the use of the magnet.



## THE DANGER TO THE HEARING APPARATUS IN MODERN WARFARE

By WALTER A. WELLS, M.D., A.M., F.A.C.S.  
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The object of this discussion is not to produce undue alarm but to point out and emphasize before it is too late the extraordinary hazard to which the hearing organ is exposed by the implements and methods of modern warfare.

We stand aghast, and rightly so, at the destruction being wrought upon great buildings, great institutions, great centers of science, culture and art. But it is of importance that we realize too that destruction is being wrought upon personal values—upon man himself.

It is right that we deplore the loss of great masterpieces of art, the highest achievements of genius. But we should understand that in the loss of hearing we are losing a great masterpiece of nature, the highest achievement of the evolutionary process.

Biologists tell us that the hearing is phylogenetically the latest and most elaborately developed special sense. Certainly no one can view the complexity of its anatomical structure without being profoundly impressed, and as to its function, when we consider its sensitiveness to sounds (even to the infinitesimal faintness of  $1/1000$  of a dyne, equivalent to one billionth of atmospheric pressure), together with the extraordinary range of intensities to which it can respond (up to one billion times the threshold value), and when we consider the number and diversity of its sense qualities, we feel that we may rightly claim that here indeed is a consummate work of nature, not surpassed by any consummate work of art.

But what is more to the point is that it is of great practical value in the human economy, and what is especially apropos in this connection is that it is of vital importance to successful warfare. A soldier without hearing was never at any time more than half a soldier, by reason of his usefulness in detecting the approach of an unseen enemy—and today this is truer than ever before.

The recent remarkable scientific advances growing out of the discovery of the electrotonic valve have made the listening device an indispensable equipment in modern defense, especially for submarines and airplanes. The principles of acoustic science too are much utilized in signalling and in the field of communications in general. Furthermore, it is the well-trained sensitive ear that first detects significant variations in the vibrations of a motor, whether it be of the submarine plowing the depth of



the ocean or of the tank hurrying over the surface of the earth, or the plane navigating the regions of the upper air

Now noise is an inevitable by product of the machine, and unfortunately as we have learned it is at the same time a deadly poison to the ears. The more powerful the machine, the more intense the noise—and it has been proved over and over again that if the hearing organ is exposed to sounds of very great intensity, or for too long a time or too often to sounds of moderate intensity, the delicate sensory nerve cells of the hearing organ become paralyzed and ultimately degenerate.

Is it not the bitter irony of fate that the machine made for the destruction of the enemy often turns its destructive force upon its master, wounding him, as it were, in a way to weaken his mastery?

There are certain considerations with regard to the evil effects of noise upon the hearing apparatus that render it a matter of grave concern. They are namely, that (1) noise deafness in the presence of the active cause tends to grow progressively worse, (2) that it pursues an insidious stealthy course in that direction and (3) that having once reached an advanced stage, recovery is impossible.

(1) An artillery man with his ear too close to his gun will some times, after a single fire, experience an uncomfortable feeling in the ear with tinnitus and partial loss of hearing. If there be, however, no repetition, the symptoms will disappear and the ear will return to normal. But if he disregards the warning and continues day after day at the same practice, there is danger of severe and permanent deafness.

There occurs likewise a gradual deterioration of hearing from exposure to a *continuous* intense noise such as that of modern tanks, war ships and airplanes.

(2) The insidiousness of the injury depends upon the fact that in the beginning only the upper frequencies of the scale are involved. As it happens, the conversational range is practically unaffected. Therefore unless an audiometer test is made, the victim may have no suspicion of his approaching fate.

(3) Noise deafness is a nerve deafness and the ultimate pathologic result is degeneration of the special sensory nerve elements. For this type of deafness medical science has as yet no effective cure.

Our subject confines us to the discussion of injury to the hearing apparatus but located in the same structure with it and in very close anatomical association is the so called static sense, which has its seat in the semi circular canals of the posterior division of the labyrinth. Involving as it does the function of orientation and motion sensing the static sense is naturally of great importance in aviation.



## *The Danger to the Hearing Apparatus in Modern Warfare*

It becomes sometimes secondarily involved in diseases and injury of its labyrinthine neighbor, but on the whole it has a relatively better resistance.

The chief causes of injury or disease affecting the hearing apparatus in connection with warfare are: (1) infection, (2) direct trauma, (3) excessive noise, (4) violent explosions, and (5) sudden barometric changes.

1. As regards infection, it is to be hoped that the recent marked advances in hygiene, immunology and therapy will guarantee against the devastating epidemics that have scourged the armies of by-gone days.

There will be, however, a certain danger as result of close personal contact, and in some instances crowding, and from exposure to cold and wet, over-exertion and fatigue.

There will be the usual influenzal colds with ear inflammations and abscesses which may fare badly because of unfavorable conditions for treatment and recovery.

2. *Traumatism:* There is the same danger as in former wars of injury to the ear by direct blows.

Some part of the hearing apparatus may be involved in the thrust of a sharp weapon, or by a gun shot wound, or by the impact of a fast moving solid body, such as a shell fragment against some part of the skull.

A severe blow upon any part of the head may result in fracture at the skull base, and here the petrous bone which occupies a great part of the base in the form of a relatively inelastic wedge often gets the brunt of the impact and gives way. The signs of a basal skull fracture with ear involvement are: bleeding from the ear, the escape of cerebro-spinal fluid by way of the canal, and paralysis of the facial nerve, in association with deafness, tinnitus, vertigo. From the standpoint of the hearing apparatus it is important to distinguish between the transverse and the longitudinal type of fracture. In the longitudinal, the line of fracture passes through the roof of the tympanum or antrum but misses the cochlea. There is often a considerable hemorrhage from the middle ear. The prognosis is relatively favorable. In the transverse, the cochlea is apt to be involved, in which case the prognosis is grave. There may be little or no hemorrhage.

In any case of basal fracture the escape of cerebro-spinal fluid must be regarded as a serious symptom. This phenomenon, however, may easily be masked and overlooked when accompanied by free bleeding.

The most important advice to be given as regards treatment of the



ear in all cases of basal fracture is *primum non nocere*. The young aural surgeon when consulted is very prone to feel that he is called upon to do something but the fact is the least intervention the better.

A blood clot should be left in place the ear should not be syringed. Treatment should be confined to protecting the ear by simple antiseptic bandage. Then with the patient put to rest we must leave the result to nature.

Concussion of the labyrinth without a basal skull fracture although doubted in some quarters is in our opinion a definite entity. The best proof of this is the frequent observation of complete deafness on the side opposite from the side of the fracture. The exceptionally protected position of the labyrinth however leads us to believe that it will suffer concussion only as a result of a major blow and as a complication of concussion of the brain.

The organ of Corti it may be recalled is the only sense organ which lies suspended in a fluid medium. This it would seem ought to guarantee an extraordinary degree of immunity.

Let us now consider injuries of the ear due to causes that were of little importance in previous wars but in the present war play a major role. These causes are viz excessive noise violent explosions and sudden and extreme variations in barometric pressure.

**Excessive Noise.** Conclusive evidence of injury to the hearing organ as a result of excessive sound is derived (a) from the history of workers engaged in noisy occupations (b) experiments on animals and (c) pathologic study in both instances.

For a long time it has been recognized that workers in certain machine shops—boilermaking and the like—frequently experienced a deterioration of hearing and careful surveys showed that the defect was often present in a startling high incidence and degree.

The degree is generally proportionate to the duration of the occupation terminating in some cases in a complete deafness.

When opportunity has arisen to examine such cases after death degenerative changes have been found in the organ of Corti most marked at the junction of the 1st and 2nd whorls of the cochlea.

The ill effects of noise upon the auditory apparatus has furthermore been confirmed by animal experiment performed by different observers in different ways.

Animals have been exposed to all sorts of noise as bells whistles and explosions of varying intensities and of varying duration and the effects carefully studied. High pitched shrill piercing grinding noises seemed to have the worse effect.



## *The Danger to the Hearing Apparatus in Modern Warfare*

It has been found that the injury is decidedly aggravated when the animals are so placed that much of the sound is conveyed by bone conduction.

Noise is an outstanding feature of modern warfare. It is the necessary accompaniment of mechanized units and of expanded artillery.

It is encountered on every hand. It is attendant upon efforts of defense as well as offense, and its evil effects often fall upon noncombatants as well as combatant troops, upon civilians as well as soldiers.

Noise, moreover, is a favored weapon in blitzkrieg tactics, because being biologically associated with the emotion of fear, it is supposed to strike terror into the hearts of the enemy.

Two kinds of noise are most in evidence—the sudden loud explosive noise of artillery fire, and the steady grinding noise of motorized fighting machines, especially tanks and airplanes and warships.

Drew Middleton, Associated Press correspondent, in a recent graphic description gives you some idea of the noisiness of tanks in action. To quote in part: "An inch from your face," he writes, "is a telescope calibrated for firing by the tank's 2 pounder and the Besa-machine gun. . . . The commander's voice crackles through your earphone. 'Here we go!' he cries, and the cruiser tank swings into action with a tetrific grinding noise. . . . It's like the engine room of a ship; every available inch is filled with machinery, levers, dials and ammunition. The steady clack-clack of the tracks and the pounding roar of the motor deafens you. . . . Curiously," he remarks, "the crew carries on efficiently and seems unaffected by the racket of the motor. They fire the tank's 2 pounder on the range and the recoil whips past the gunner's ears. There's the banging of the semi-automatic breech opening. . . . Next the Besa-gun fires at full speed. The noise of its report is deafening. Bullets pierce the shell of the target like cheese and crash into a brick wall behind. After it's all over you talk to the driver, who was a school teacher before the war. He says the firing doesn't disturb him because he has too much to do."

Noise intensities are too often beyond auditory endurance. The upper limit of the human ear is gauged at its best about 130 decibels, beyond which sound becomes feeling, often a painful feeling. We have recently seen some data as to the noise of a modern warship; in the average stateroom, with full power on, it measures 80 decibels; in the boiler room, with speed 10 knots, 95 decibels; in the steering engine room, speed 15 knots, 100 decibels; in the boiler room, full power on, 125 decibels!

The rigid steel construction serves to accentuate the noise, and it favors transmission of the powerful vibration directly to the body, and



through the bone to the inner ear. Such heavy steel framework is probably necessary to the defensive strength of the ship, but some means should be found at least to dampen the vibrations of the partition walls and floor.

In some machine shops thick floor mats are provided the operator to stand on because of their insulating value against vibrations.

*Explosions* A feature of the present war, which goes far beyond anything of the kind in previous wars, is the monstrous bombs dropped from the air over enemy territory. Exploding with terrific effect they level to the ground buildings of supposed firm foundation.

Professedly aimed only at military objectives, they are nevertheless destroying monuments, museums, institutions of learning, private residences, churches and hospitals.

Many peaceful citizens too are victims, and when they are not killed they are often visited with what is comparatively a new kind of disability, a loss more or less severe and more or less lasting of their sense of hearing—in some cases, sad to say, a complete and permanent annihilation of that treasured faculty.

We are beginning now to get some medical reports of the subject from the warring countries, not as complete and detailed as we would like but enough to make us realize that it is a serious problem. One indication of this too, is the fact that in some localities ear defenders of one kind or another are being distributed to the civilian population. We are told that on the occasion of an air raid many eardrums are being smashed. How could it be otherwise? The tympanic membrane, according to reliable tests cannot ordinarily stand a pressure greater than five to seven pounds to the square inch. On the explosion of these super bombs a pressure is set free amounting at the center to as high as 200 tons to the square inch and of such force that it shatters all the window glass for blocks in every direction. The expansion of gas gives rise to a great compression wave followed immediately by a wave of rarefaction and it is this latter, it is claimed which injures the drum.

It acts upon the ear canal like a great exhaust engine, tearing out the membrane and the attached ossicles.

A simple rupture of the drum membrane is as of course we all well know not in itself a serious casualty.

In fact, as Politzer pointed out some years ago, there is reason to believe this accident has its favorable side in that it lessens the effect of the explosion upon the inner ear. It is injury to the inner ear that is of grave significance and there is no doubt that this may occur. Such reliable authorities as Bunch and Hughson have reported cases of com-



## *The Danger to the Hearing Apparatus in Modern Warfare*

plete deafness even from the mere explosion of a fire-cracker close to the ear. Complete deafness does not occur from a mere middle ear lesion, no matter how severe. What organic change occurs in the inner ear structure is not exactly known, but in some cases hemorrhagic extravasations have been found in the nerve elements, and in some cases the nerve elements appeared to be torn or displaced.

In regard to treatment, the most important is prophylactic. Ear defenders should be worn by all those who are in imminent danger from exposure. A good illustration of the value of some sort of sound dampening in the ear canal is to be found in the observation that those individuals whose ears happen to be filled with an accumulation of wax are less likely to suffer than their wax-free neighbors. Ear protectors are helpful even though they afford only a limited insulation owing to the fact that auditory sensation is not directly proportionate to the intensity of the sound.

It follows rather the Weber-Fechner law applicable to all sense organs, according to which the physiological effect is roughly proportionate to the logarithm of the energy of the stimulus.

Therefore, with as little as even a 10 per cent reduction as measured in decibels, one may have as much as a 50 per cent reduction in perceived sensation.

The trouble is that most of the devices employed as ear defenders do not cut down the decibel reception even the little degree that is required. We have demonstrated by careful audiometer tests that the insulating value of the little hollow rubber tube (glove-finger type) generally recommended is almost nil. We found, however, that if we inserted into the hollow rubber tube a small hard rubber obturator, its effectiveness was measurably increased.

This is easy to understand because, for one thing, the obturator inside provides additional insulation, and for another, which is more important, it enables you to press the device well into the canal, giving it a snug fit.

Accordingly we have had made for us by Meyrowitz an ear-defender of this pattern, and you can readily see by the accompanying audigram how much more effective is the insulation than that obtained by the ordinary hollow tube type, viz., twenty to thirty decibels as compared to less than ten.

It has besides the advantage that it can be adjusted to suit existing conditions; worn loose if one needs to hear conversation about him, pressed tightly in if one desires as much as possible to shut out all sound.

*Barometric Influence:* It remains to speak of one other factor which

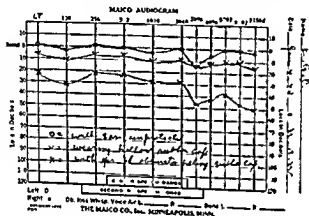


has come into play as cause of ear trouble in the present war

We refer to the violent fluctuations of air pressure to which military pilots are exposed in altitude flying

In the last war planes seldom flew higher than 10,000 feet and seldom at a speed exceeding 150 miles an hour

Today they fly frequently at an altitude of 15,000 to 20,000 feet, and some go to 30,000 or 35,000, and at a speed of 300 miles an hour, some of the new bombers are geared for the prodigious speed of 400 to 450 miles an hour



The change from a low altitude to the high, when accomplished at high speed subjects a pilot to violent sudden change in atmospheric pressure, which places a severe strain upon the hearing organ

The significance of the barometric fluctuations for the ears lies, of course, in the fact that the middle ear cavity contains air, which for healthy function must be maintained at a pressure corresponding to the surrounding atmosphere

This equalization is accomplished by the Eustachian tube, which though normally closed by apposition of its walls, will open for passage of air as needed

Capt Armstrong who has made a special study of the effects of aviation upon the hearing organ, finds that many persons flying even at moderate height develop a condition which he refers to as *aero otitis*. They complain of an uncomfortable feeling sometimes amounting to real pain with some deafness tinnitus and mild vertigo. Most cases clear up promptly on return to normal atmosphere

When very great heights are attained, other factors, too, come into play, which can have a profound physical and even mental influence

At extreme altitudes terrific cold is encountered. The temperature in



## *The Danger to the Hearing Apparatus in Modern Warfare*

climbing drops about 2° C. for each thousand feet ascent until 35,000 feet is reached. The pilot will usually suffer greatly from the cold at 20,000 feet; he generally finds it unbearable at 25,000 or 30,000 feet.

A lack of oxygen in the upper atmospheric strata is a yet more serious matter.

At the very great height to which fighter planes are sometimes obliged to ascend, anoxemia may prove a greater danger than the enemy fire at lower levels. On reaching 20,000 to 25,000 feet the vision becomes blurred, and hearing so lowered that the sound of the engine is imperceptible and there may be a paralysis of the arm and leg muscles. There is, besides, danger of aero-embolism. Yet, strange to say, the physical deterioration is often accompanied by a feeling of well being and that everything is all right, even to the point of exhilaration. The danger of some untoward occurrence is thereby heightened. Regulations require use of the oxygen tank on reaching 18,000 feet; for extreme altitudes the closed pressure cabin is indispensable.

Dive bombing is an ordeal which only the hardest and specially trained aviators can attempt. From a height of 25,000 feet the plane is turned vertically downward to descend at the terrific speed of 500 or 600 miles an hour, and then when nearing the earth, turned again suddenly into a horizontal direction. The abrupt change at this speed is bound to profoundly affect the pilot. Centrifugal force drives the blood from the cerebral vessels and brings about a temporary unconsciousness. If we add to all these hazards that incident to the engine noise, we cannot easily overestimate the possible injury to the organ of hearing.

Many surveys have been made among civilian flyers and they generally show an undue loss of hearing in five to ten per cent of all cases, with a disproportionate loss in bone conduction. When we shall have some authentic tests of military aviators the results we fear will be much worse. Can nothing be done to avert these harmful effects of flying upon the auditory organ? The answer is yes, something, but a long way from enough. The danger will remain until some radical improvements are made in aviation construction and aviation methods, which will have more regard to the physical limitations of the pilot.

Certain precautions, however, may be observed. Good labyrinthine function must be held as an important preliminary requirement for all flyers. Formerly much stress was placed on the necessity of having normal static function. It is equally if not of greater importance that he have healthy hearing function.

It is especially vital that there should be no Eustachian obstruction. A bad head cold is for this reason a contra-indication for flying. Inci-



# FIRST AID AND EMERGENCY TREATMENT OF GUNSHOT WOUNDS OF THE JAWS

By COLONEL ROBERT H. IVY, M.D., D.D.S.

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Experience gained during the last war and with injuries of the face and jaws subsequently seen in civil practice teaches us that provision should be made for adequate specialist care as early as possible. By proper early fixation of fractures and attention to soft tissue wounds, the time of invalidism is greatly shortened, and the end results more nearly approach perfection.

Preparations have already been made in the office of The Surgeon

General for a more systematic plan of treatment of these cases in war time than was possible during the war of 1917-18. Instructions are being prepared for the handling of jaw injuries by medical department units from the combat zone back to the general hospital so that a uniform plan will be followed. Special training is being given to medical and dental officers and enlisted men of the medical department who will be assigned to units from the combat zone back to the general hospitals.

The most efficient treatment of face and jaw injuries entails close co-operation between officers of the medical and dental corps. The general care of the patient, the problems of wound infection, and tissue repair will be largely in the hands of the medical officer, while the special problems of fixation of jaw fractures and care of the mouth and teeth lie within the field of the dental officer. In meeting the emergency, it is expected that courses of instruction will be given to medical and dental officers who have been selected as specialists in this particular field.

By carrying out a correlated plan of treatment from the advanced zone to the installations in the rear, it is expected that the average period of disability of these cases of jaw injury will be greatly shortened, and a larger number will be restored to approximately normal function and appearance than if haphazard methods are followed.

The most advanced organization to which specialists in the care of face and jaw injuries are attached is the surgical hospital, a mobile unit, operated in connection with the clearing station, located seven to ten miles to the rear of the front line. Each surgical hospital has a maxillo-facial team, consisting of a surgeon and a dental surgeon, well trained in the special requirements of treatment of these injuries. Before reaching the clearing station and the surgical hospital, however, the wounded man may receive emergency care from the company aid men and the



battalion aid station, to which no specialists are attached, but where the enlisted men and the battalion medical and dental officers have received certain instruction in the use of emergency equipment with which they are provided. I wish to point out first some of the things that can be done at these advanced posts by the medical personnel which will probably save many lives and facilitate the later treatment of face and jaw wounds by the specialists.

Every officer and soldier of the medical department in the combat zone is supplied with equipment useful in rendering first aid treatment for jaw injuries. The first aid packet itself is well adapted for jaw fractures and can be applied suitably for a great many types of gunshot wounds of the face and head. The compress, sewn to the central portion, can be made to serve as a hammock or sling to support the injured structures. By tearing the attached bandage lengthwise, the dressing becomes an ideal four tailed bandage which may be securely and satisfactorily applied by officer or enlisted man. The compress itself can be separated from a bandage and used as an extra packing, dressing, or support over any region as may be necessary. The safety pins in the first aid packet assist in making the dressing secure. With the aid of common rubber bands or elastics and the safety pins, emergency fixation can be applied with bandages, adhesive plaster, etc. Anchorage for the bandage may be secured by attachment to the over seas cap with safety pins and rubber elastics.

The points demanding special attention in the combat area may be formulated as follows:

- 1 Arrest of hemorrhage
- 2 Provision of adequate respiratory airway
- 3 Temporary approximate reduction and fixation of bone fragments
- 4 Provision of safe transportation from the combat zone to a hospital in the rear

*Arrest of hemorrhage* Moderate hemorrhage from a wound about the jaw can usually be checked by pressure from a gauze pack inserted in the wound and held in place by a four tailed bandage. The latter will also give some temporary support to a fracture of the mandible. Care must be exercised in the application of the pack and the bandage so as not to increase any respiratory difficulty occasioned by the nature of the wound itself. Hemorrhage that cannot be checked in this way demands a search for the bleeding vessel and application of a clamp to it, followed by ligation if ligature material is available, otherwise



the clamp should be left on during transportation to the advanced hospital.

*Provision of adequate respiratory airway:* Loss of bone and muscle attachment frequently results in loss of control of the tongue with danger to respiration. This is best controlled by use of a long suture through the tip of the tongue. It should be long enough to draw the tongue forward and may be attached to the dressing. A piece of gauze or bandage may be tied to the suture for traction to clear and improve the air passage. These considerations are particularly important if the patient is unconscious. In other cases, due to swelling of the soft tissues, sufficient airway can be provided by the insertion of a rubber tube through the nose, or the mouth, to the nasopharynx. Tracheotomy should be considered only as a last resort since it is followed by a high mortality in cases of this type.

*Temporary approximate reduction and fixation of fragments:* If a dental surgeon is available, he should be assigned the problem of temporary fixation. Each dental surgeon at advanced stations is provided with an emergency maxillo-facial kit, which contains instruments and materials for emergency dental operations and for application of temporary fixation of fractures of the jaws. Intelligent application of emergency treatment reduces the period of hospitalization and assures far greater success in subsequent treatment with a minimum of deformity.

Early treatment should be such as to assure every chance for the restoration of original occlusion of the teeth, or the restoration of the function of mastication, even in those cases with considerable loss of bone. It is particularly important that the collapse of bone segments be avoided. In the removal of tooth fragments, foreign matter, particles of bone, etc., one must remember that these are elements which invite infection, and early cleaning of the wound is essential. Often bone particles which still possess periosteal attachment are removed. This should never be done since this small living attachment may make all the difference between new bone formation and restored function, or collapsed fragments and the attendant complications. Even comminuted viable bone should be saved. Reduction and fixation can only be controlled by skillful manipulation of the segments and the application of simple measures by means of elastic traction and special bandages.

Wiring of teeth of the same jaw across the line of fracture may be used in some cases to maintain fragments during evacuation to the rear, but fixation of the lower to the upper teeth should never be used prior to unattended travel. Fixation is important at this stage, for stabilization



of the fragments helps to reduce pain and shock. It also assists in the control of the tissues essential for the maintenance of a clear air passage. Stabilization is necessary to avoid recurrent hemorrhage and facilitate recovery. Military conditions may permit the application of some of these fixation measures by the dental officer at the battalion aid station. If not they must be deferred until the wounded man reaches the surgical hospital or the evacuation hospital.

Fractures of the superior maxilla frequently displace the loose structures downward and backward and definitely interfere with respiration. In case of a bilateral comminuted fracture of the posterior part of the mandible the anterior part of the jaw may drop backward and likewise cause serious interference with respiration. In a case of this kind the front of the jaw may be held forward by a simple emergency splint developed at the Walter Reed General Hospital and found practical in several cases. The only articles necessary are two or three wooden tongue depressors, adhesive plaster, a two inch bandage, and the ligature wire supplied with the emergency maxillo-facial kit. Two tongue depressors are placed end to end and fastened by means of a third overlapping them in the middle with adhesive plaster. This is secured with a bandage vertically in the frontal region with the lower end extending in front of the chin. A wire is passed around the lower front teeth or around the chin segment of the mandible and the ends of the wire fastened to the lower end of the tongue depressor piece. The spring of the tongue depressor piece will effectively keep the anterior segment of the mandible forward. In the case of backward displacement of the upper jaw forward traction can likewise be made by attachment of the upper front teeth to this apparatus.

In the large gaping wounds of the soft tissue of the face one may be tempted to try closure early by suture. This should never be done before at least temporary fixation of bone fragments otherwise collapse of the latter will occur with great deformity and interference with function. In such cases it is better after fixation of fragments not to attempt closure of the soft tissue wound but to suture skin and mucous membrane edges together in order to cover exposed ends of bone and wait for healing before attempting repair of the gaps in the soft tissues.

*Provision of safe transportation from the combat zone to hospitals in the rear.* Transportation or evacuation from the combat zone places a certain responsibility on the medical department units for casualties must be prepared for safe unattended travel by ambulance or hospital train to general hospitals. Nourishment, sedation, prevention of further shock, comfort and safety are all essentials which medical attention



## *First Aid and Emergency Treatment of Gunshot Wounds of the Jaws*

must secure for the greatest number. Lessons in past wars are convincing proof that ambulant or semi-ambulant cases with oral or pharyngeal wounds should sit up. If he must be recumbent, the patient should be placed face down if there is any danger of obstruction in the air passages. These precautions lessen the mortality rate of jaw injuries during evacuation.

The time required for the wounded to reach the general hospital which may be situated 100 miles or more to the rear of the front line varies considerably. But the desirability of rapid evacuation to the place where definitive treatment can be given is obvious. The measures outlined above, if carried out properly, will insure the arrival at the base of a large percentage of cases of jaw injury in good condition for definitive treatment. In the general hospitals, every possible facility is provided in the way of equipment and special personnel for the proper care of these cases. On admission, each case will be examined jointly by the surgeon and the dental surgeon, and a plan of treatment outlined.

In the interval between receipt of wound and arrival at the general hospital, the onset of infection is to be looked for, hence, measures for combating infection constitute one of the first considerations at this time. Wounds should be carefully revised, previously overlooked foreign bodies removed, abscesses opened, and proper drainage established. Local and general chemotherapy should be employed when indicated by cultures. X-ray examination will reveal foreign bodies, fractured teeth, displaced bone fragments, etc. As the acute inflammation subsides, more permanent appliances for reduction and fixation of bone fragments may be made. The important principle of early reduction and fixation of bone fragments before attempts at permanent soft tissue repair should always be borne in mind. This will avoid collapse of underlying bone fragments.

After the infection has cleared up, the problem of repair and replacement of lost tissues is to be considered. The soft tissue repair, by means of flaps, grafts, etc., may often be undertaken while the fractures are undergoing treatment. In about ten per cent of gunshot fractures of the lower jaw, there is so much loss of bone substance that non-union results, and the necessity for bone grafting arises. No attempt at bone grafting should be undertaken until at least three months after disappearance of infection from the region of injury.

The final steps in restoration of these cases are the provision of artificial dentures to replace lost teeth, and prostheses of various kinds to supply artificially missing parts that cannot be restored by surgery.



# RUPTURE OF THE DRUMHEAD AS A WARTIME INJURY

By ALFRED B ALEXANDER MD, LRCS

Rupture of the drumhead is a common peacetime injury, and when the present emergency has become a matter for clinical statistical investigation rather than for clinical action, and more complete statistical figures are available it might well prove the most common of all types of injury due to aerial bombardment. The frequency of rupture of the tympanic membrane under air raid conditions is no surprise. Reports from Barcelona had suggested it, and in a recent discussion Miss J Collier (1940) quoted R Trueta's Barcelona figures indicating that from 30 to 60% of the Barcelona air raid casualties had sustained damage to the drumhead.

Rupture of the tympanic membrane in peacetime is a slight injury. But it only remains a slight injury when it is followed by an uncomplicated course free from infection of the tympanic cavity, and there is evidence to believe that this uncomplicated course, which is the rule in peacetime injuries, is less frequent when the injury is due to the blast of high explosive bombs. Once infection establishes itself inside the tympanic cavity the whole chain of aural afflictions and otogenic complications ranging from slight persistent deafness to death from meningitis is a possible outcome of the injury.

Apart from those ruptures of the tympanic membrane which are caused by the extension of a fracture of the cranial bones to the membrane it is customary to differentiate between direct and indirect traumatic ruptures. The direct ruptures are caused by a great variety of foreign bodies and by over powerful syringing of the meatus for the removal of wax. The indirect ruptures are due to sudden changes in the density of the air in the meatus aided by complete blockage of the air in the meatus at the moment of the influence of the force. The most common causes of such indirect ruptures are blows on the ear particularly the slap with the open palm occluding the meatus and inadequate head first dives into the water. Most textbooks include the rupture of the membrane due to explosions among the indirect ruptures but this is wrong. The rupture is a direct one caused by the extremely powerful concussion of the air by the explosive—the wave of pressure (Zuckerman 1941). All these differentiations however are only of theoretical interest.

From the practical point of view it is best to distinguish between ruptures which leave the tympanic cavity most probably sterile (slap on the ear) and ruptures in which the sterility of the tympanic cavity has



## *Rupture of the Drumhead as a Wartime Injury*

been interfered with (syrringing, diving). These two clinical types of rupture are often followed by a different clinical course. Ruptures of the drumhead caused by blast must be regarded as belonging to the second group, as it is always likely that foreign matter, carried by the blast, has entered and possibly infected the tympanic cavity.

### **Symptoms**

Indirect ruptures of the drumhead can remain symptom-free, particularly in cases of previously reduced hearing or diminished resistance of the membrane. In air-raid casualties the symptoms are often masked by the presence of more severe injuries and, lacking routine otoscopy, such cases are in danger of being overlooked until suppuration occurs.

In most cases, however, at the moment of the rupture a short stabbing pain is felt, frequently accompanied by tinnitus or the hearing of a high-pitched sound. Initial vertigo is very common. Some pain persists for a few hours or even days. Hearing is moderately reduced. In many cases a trying feeling of fullness in the ear, occasional giddiness and sickness, headaches, and a certain amount of deafness persist for considerable periods. The vertigo, particularly that immediately following the injury, deserves a few words of explanation. It is not, as commonly suggested, caused by some "concussion of the labyrinth," but is simply explained as being the effect of cold caloric irritation, caused by cold air. The air normally contained in the tympanic cavity is warmed by its passage through the nose and Eustachian tube. Following the injury, cold-air suddenly gains access to the middle ear and irritates the labyrinth. I have found in such cases that vertigo and nystagmus can be re-elicited, and the direction of the latter characteristically changed, by alternately placing a bottle filled with ice and a hot-water bottle in front of the external canal. The irritation of the labyrinth by cool air is one of the reasons for keeping the meatus closed following such an injury.

### **Signs**

In fresh cases the most common finding on the drumhead is that of a roundish, irregular, or slit-shaped perforation, the latter usually in a radial position. The margin of the perforation is often frayed and irregular, and sometimes a flap, exposing an angular-shaped perforation, is folded towards the skin of the meatus. These "everted edges" of the perforation are not, as recently suggested, due to the "wave of suction" that follows the pressure-wave of the blast, but are quite common peacetime findings, and are described in old textbooks. A small zone around



the margin of the perforation is discoloured and stained by the extravasation of blood. The remaining part of the drumhead is unchanged, but may show small interstitial haemorrhages, the latter findings are particularly common in blast injuries in which also minute blackish spots sometimes occur due to the impregnation into the membrane of small solid matter contained in the blast. A certain amount of blood or coagula in the meatus is a very common picture, and in air raid casualties the whole of the meatus may be blackened by soot. In fresh cases the yellow colour of the normal mucous membrane of the medial tympanic wall is easily distinguished through the perforation its yellow (bone yellow) colour forming a distinct contrast to the blood stained margin of the perforation.

The perforation is more often situated in the anterior than in the posterior quadrants. Any anatomical detail of the contents of the middle ear cavity such as stapes, chorda tympani or round window can on occasion be seen through the perforation should it happen to lie within the line of sight and such structures will show a typical parallax phenomenon on movements of the observer's head. In cases in which there is no suspicion of a fracture to the base of the skull it might be permissible to remove carefully blood crusts, coagula or wax by means of a sterile probe or aural forceps should such structures render inspection of the drumhead impossible. The use of the syringe however is always and most strictly contraindicated.

It is usually easy but quite unnecessary to demonstrate the presence of the perforation by certain tests such as the Valsalva experiment, Kugels test or reversed Politzerization. The hearing is moderately reduced, the tuning forks revealing a deafness of the conductive (middle ear) type. It is advisable to test for a reduction in the perception of high sounds and for nystagmus (other than that produced by cold caloric influence from the air) which in complicated cases reveal damage to the labyrinth.

The diagnosis presents no difficulties in a fresh case. The blood tinged irregular margin of the perforation is quite characteristic. In cases of longer standing however the shape of the perforation might have already become round and regular and the extravasated blood be resorbed. In such cases diagnosis from a pathological perforation might become exceedingly difficult unless the history helps to clear the case.

#### **Clinical Course**

Traumatic rupture of the drumhead will lead to one of the following three types of clinical course



## *Rupture of the Drumhead as a Wartime Injury*

1. *Uncomplicated Cases.*—The perforation gradually diminishes in size, while normal drumhead tissue regenerates. Complete healing ensues, and after the regeneration of the drumhead is complete it is quite impossible to recognize any trace of the site of the previous perforation. Drumhead and hearing regain perfect normality. The average duration of the healing process of such cases is twenty-five days.

2. *Infection of the Tympanic Cavity of Low Virulence.*—Minor inflammatory reactions appear within one to three days after the trauma. There is sero-purulent discharge, lasting from a few days to several weeks. Such cases often heal with the formation of atrophic scars followed by chalk deposits in the membrane, with chronic adhesive changes (synechia) in the middle ear, or with a persistent perforation. According to these changes, the hearing capacity is permanently somewhat reduced (middle-ear deafness).

3. *Infection of the Tympanic Cavity of High Virulence.*—Major inflammatory reactions, constituting the suppurative otitis media of post-traumatic origin, appear usually not later than twelve to twenty-four hours after the injury.

There are few indications in the literature regarding the relative frequency of these different types. It is obvious that ruptures which leave the tympanic cavity sterile stand a far better chance of an uncomplicated course than those in which the sterility has been interfered with. Water is the most common source of infection in peacetime, and therefore rupture due to diving or syringing is often followed by inflammatory reactions. It is a complete fallacy to think that the routine use of sterilized water for syringing could prevent infection in cases of accidental rupture, since the meatus, with which the water has always been in contact, is never sterile. However, taking into consideration both the uninfected and the possibly infected type of rupture, a survey of a large number of cases at the Neumann Clinic several years ago left me with the impression that at least some 80% of all peacetime ruptures follow an uncomplicated course to normality of drumhead and hearing. This proportion seems to be quite different in blast injuries, as over 50% of the cases caused by air raids which I have seen showed some infection of the tympanic cavity. Admittedly I am judging from a small number of cases, but the experience of a few colleagues with whom I have discussed the matter points in the same direction. It is therefore of great importance that in all cases of rupture of the drumhead caused by blast the tympanic cavity should be regarded as presumably infected, and treated accordingly.



## Treatment

The object of treatment is best expressed in T. B. Layton's words—to get well every single case under one's care. And by well I mean a dry ear, a normal drumhead, and perfect hearing. This is achieved simply enough when the tympanic cavity has remained free from infection. In such cases the treatment should be restricted to the protection of the tympanic cavity from external influences that may cause further damage. No unnecessary manipulations in the meatus should be undertaken. Syringing as well as all types of ear drops, whether containing water, peroxide, spirit, glycerin, or any other fluid, are strictly contraindicated. It is sufficient to plug the meatus lightly with sterile ribbon gauze or cotton wool, and to inspect once or twice a week. The patient must be advised to take great care while washing his face or taking a bath—or, in the case of a woman patient, while having her hair washed or set—lest water should enter the meatus. The taking of violent forms of exercise should be avoided, as sweat might accumulate in the meatus and infect the middle ear.

It is the other type of rupture, in which foreign matter has entered the tympanic cavity, that presents the problem, and, as stated above, all ruptures of the drumhead caused by blast belong to this group. Complete healing and perfect hearing are guaranteed only when the tympanic cavity remains free from inflammatory reaction. Even minor inflammatory reactions might lead to some degree of permanent deafness with all its implications, and poor results obtained during the present emergency might increase the rate of deafness among the post-war population to a very considerable degree owing to the frequency of this injury. Perfect results depend on the prevention of the trauma leading to infection. But how can a tympanic cavity contaminated by blast be protected against the occurrence of such infection?

*Insufflation of Sulphanilamide*—Impressed by the frequency with which suppuration follows rupture caused by air raids, I have recently started to treat all such cases as early as possible with a preventive insufflation of powdered sulphanilamide into the tympanic cavity. My results have so far been highly satisfactory, and though fully realizing that the results of all preventive methods are particularly liable to misinterpretation and that the experimental data at present available on the topical use of sulphonamides are not convincing, I feel satisfied that early insufflation of sulphanilamide powder into a possibly or presumably infected tympanic cavity will reduce to a minimum the number of cases of subsequent suppuration in the middle ear.



I have also tried the insufflation in cases already infected, but have failed to observe any benefit, the powder just being swept away by the discharge. And cases of acute otitis of traumatic origin should be treated by the oral administration of a sulphonamide in the same way as it is used in otitis not of traumatic origin.

*Technique of Insufflation.*—This is very simple so long as the ordinary forehead-mirror and not an electric auriscope is employed. The site of the perforation is focused, and a few puffs from a straight powder-insufflator, administered through the speculum under guidance of the otoscopying eye, are quite sufficient. It is necessary to look into the ear in order to make sure that the powder not only coats the walls of the meatus but actually reaches the tympanic cavity through the perforation. Afterwards the meatus is lightly plugged and the patient advised as to the protection of his external canal.

The insufflation of powder into the middle ear is so simple, the results are so promising, and the aim of preventing infection is so important that I have no hesitation in recommending it as a routine treatment for rupture of the drumhead in the present emergency. It can cause no harm whatsoever, and if tried on a large scale and found successful it will also serve as a further argument in the demand for the routine otoscopy of all air-raid casualties.

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## GUNSHOT WOUNDS OF THE HEART

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It is interesting to realize that though wounds of the heart are fatal in the great majority of instances there is undoubtedly a residue of cases, small though it may be which recover

In warfare a wound of the heart is seldom an isolated lesion, and is often accompanied by serious damage not only to the thorax but to other parts of the body. In 1920 the late Sir George Makins reviewed the specimens of gunshot wounds of the heart which had been brought together in the War Office Collection at the Royal College of Surgeons. These specimens showed that the heart may be almost blown to pieces or very severely lacerated and that missiles may pass through the viscera to be lodged elsewhere or be retained in the auricles, in the ventricles or in the walls of these cavities. Like all war wounds, some are apparently aseptic while others are associated with the severest forms of infection. Since the war of 1914 18 many cases have come to light in which missiles have been retained in the heart and the patients have not only survived but have been able to pursue more or less normal activities years afterwards. Injuries less easy to detect, like bruises, contusions and superficial lacerations of the heart wall, probably also occur in warfare from bursting bombs etc. but with external wounds. Such trauma must sometimes be the cause of temporary or even permanent disability.

H. Ryerson Decker (1939) was able to review no fewer than 100 cases in which foreign bodies had been retained in the heart of surviving patients, and of these 65 were either bullets or fragments of shell. In most of these cases the stage of infection had passed and the foreign bodies were located by x-ray examination, often long after the casualty. When it has been possible to examine the seat of the lesion at operation or at necropsy the foreign bodies have usually been found safely surrounded by a barrier of strong fibrous tissue (Couteaud and Bellot, 1914-15), and sometimes with a collection of fluid round about them. The cause of death on the field or soon afterwards are the great severity of the injury, shock, or haemorrhage, and under haemorrhage comes the question of cardiac tamponade. Later deaths are due to sepsis, to embolism, or to associated injuries.

### Acute Cardiac Tamponade

Cardiac tamponade is a most interesting condition, but for the moment we are only concerned with the acute variety. In many cases of gunshot



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wound the missile seems to penetrate the wall of the heart without causing haemorrhage, while in others there is free bleeding. If the blood cannot readily escape from the unyielding pericardium this sac becomes rapidly distended and the volume of the accumulating blood exercises pressure on the veins and, later, on the walls of the auricles. In this way the cardiac action is embarrassed and finally arrested. The rate of development of the tamponade depends on the size and situation of the wound of the cardiac muscle and the ease with which the effused blood can escape, either externally or into the pleural cavity. The symptoms are quite characteristic. After a latent interval of varying duration, which may be as short as ten minutes, the patient complains of oppression at the heart and of fear, and is uncontrollably restless. The countenance, at first pale from shock, becomes cyanosed, the body surface is cold and there is profuse perspiration, while the big veins at the root of the neck are overdistended. The quick pulse become irregular, and as the heart falters its beat becomes fluttering in character. Naturally the blood pressure is low and rapidly falls as the patient sinks into unconsciousness. Examination reveals the signs of distension of the pericardium, as shown by the greatly increased dullness, while the heart sounds are muffled and obscure. The condition is rapidly fatal, therefore it must be recognized promptly if effective aid is to be given. The essential step is to open the pericardium freely so that the accumulated blood can escape; the heart requires living room and must be immediately decompressed. Cokkinis says: "Every patient who reaches the theatre with the least evidence of cardiac function should be operated upon, as even in the most desperate case the compressed heart may revive immediately the pericardium is opened."

Of course, if after the release of the intrapericardiac tension the bleeding continues the heart must be exposed in order that the wound may be sutured, for preservation from one sort of haemorrhagic death will bring no credit to surgery if the patient is to succumb from another. Though merely to enlarge an entrance wound may save death from tamponade, it is so likely to be necessary to deal with the wound in the heart itself that the surgeon should be prepared to carry on there and then with the complete operation. The technique to be employed is described below.

### **Diagnosis of Heart Wounds**

The diagnosis of wounds of the heart is suggested by a situation near the cardiac area, but in many cases the wound of entrance has been in the lateral wall of the chest, in the axilla, or even through one or



other upper extremity. With a missile impacted in the heart there is very often no characteristic disturbance, and the suspected diagnosis can only be confirmed by radiography. But even the radiograph may be deceptive for foreign bodies in the pericardium frequently reveal a pulsation which is merely communicated. The only thing to do is to accept the probability of a heart wound when a missile has entered within the cardiac area and not to overlook the possibility with wounds in other situations. The exact diagnosis of the position of the missile will usually be a matter for a subsequent and more detailed investigation. But another type of case occurs in which the wound has destroyed some part of the parietes and there is a direct and obvious communication between the outside and the heart. These open wounds are not necessarily the most grave. Generally speaking, wounds from shell fragments are more serious than those inflicted by bullets, and this is largely due to the common association of sepsis with shell wounds.

### Emergency Treatment of Shell Wounds

Perhaps it is better at this stage to deal with the treatment of such wounds as are obvious emergencies, these include the open wound from shell fragments as well as the wound in which cardiac tamponade rapidly develops. In the open wound the indications are to arrest haemorrhage, to treat shock and to anticipate sepsis. These indications can be met by approaching the matter as with wounds in other situations and it will be necessary to excise the wound in the parietes, to inspect the heart to suture any laceration in the viscus which is bleeding, or to remove a foreign body that is easily accessible. Foreign bodies that are deeply embedded in the heart wall or are lying in the heart cavities are probably best left alone at this stage. The temptation for the surgeon to go on is very strong but generally speaking deaths are not due to the mere presence of the foreign bodies and if the patient survives the risks of haemorrhage and sepsis the problem of the foreign body can be considered with deliberation later. In this sort of case it is probably wiser to provide for drainage of the pericardium by tube or rubber tissue which may be safely placed in the lowest part of the sac or even up behind the heart.

Many of those who have recorded otherwise successful interventions in gunshot wounds of the heart have had to regret late deaths from infection and have sometimes expressed the conviction that drainage might have staved off disaster (Ballance). The local use of some anti-septic will follow the practice that may be in vogue at the time, for the



heart and pericardium are quite capable of withstanding such treatment. The resources of chemotherapy may be most valuable.

### **The Best Method of Exposing the Heart**

The wound of the parietes may be sufficiently extensive to give access to the interior of the pericardium and the injured area of the heart. As a rule, however, these wounds are not big enough to enable the necessary manipulation to be carried out and some deliberate method of exposure must be adopted. If the pleural cavity is already opened the original wound may be freely enlarged along the line of a rib.

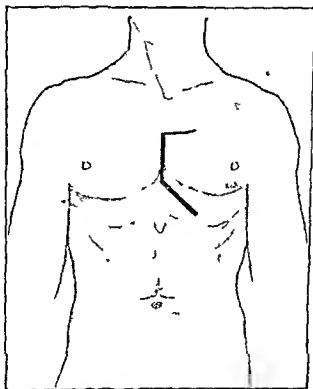


FIG 1—Incision for exposure of the heart. The primary incision along the sixth rib is indicated by a broad line while the transverse cut along the third (or second) rib is represented by a finer line. (Modified from *Textbook of Operative Surgery* by Theodore Kocher.)

By spreading such a wound and enlarging the tear in the pericardium a sufficient exposure may be obtained. But when the pleura is intact it is much better that it should remain so and in these circumstances the parasternal exposure of Theodore Kocher is very satisfactory. The steps of this operation are as follows:



1. Incise from centre of sternum along the sixth costal cartilage as far as the mammary line.
2. Separate the perichondrium and excise the cartilage. The separation should be begun at the sternal end, the junction with the seventh cartilage being divided.
3. Divide the triangularis sterni muscle close to the sternum. Gently thrusting this muscle outwards will carry the pleura out of harm's way and will expose the pericardium.

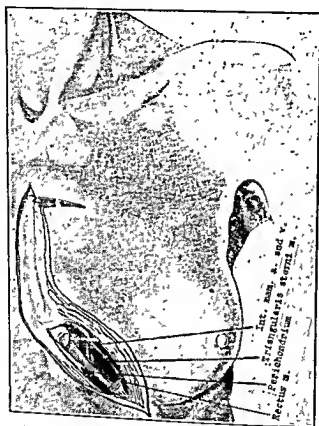


FIG. 2.—Exposure of the heart. The skin and fascia are divided and the sixth costal cartilage resected. The perichondrium is exposed lying on the triangularis sterni, on which also the internal mammary vessels descend. (Modified from *Textbook of Operative Surgery*, by Theodore Kocher.)

4. Open the glistening pericardium either now or at a later stage.
5. To secure more room make a vertical incision over the middle of the sternum to the level of the third or even second rib, and a short incision along this rib cartilage.
6. Separate the structures from the front of the sternum outwards until costal cartilages are exposed.



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7. Divide the fifth, fourth, and third cartilages at their inner ends.  
8. Lift up the flap of the chest wall with a view to turning it back. Do this slowly and gently, pushing the pleura outwards as the cartilages are lifted.

9. Break the cartilages at their junction with the ribs, thus exposing a considerable area of pericardium.

10. Open the pericardium along the edge of the sternum and, if necessary, outwards at the lower edge of the exposure.

11. To secure further space use *rongeur* forceps to cut away the remains of the sternal ends of costal cartilages and, if required, part of the edge of the sternum.

The steps of the operation are shown in the illustrations (Figs. 1, 2, and 3).

The transternal route—splitting the sternum vertically and separating the halves with a spreader—is sometimes recommended, but this is a severe operation and does not seem to have adequate compensating advantages. But whatever method of exposure is employed it will be found that the heart itself is difficult to handle and that the movements prove more embarrassing than would be expected. During systole the walls become stony hard, and the very short diastole gives very little opportunity for palpation. The organ may be pushed to one or other side or may even be partially rotated without interfering with the heart action, but handling about the base or lifting the viscus forwards usually makes the rhythm very irregular and tumultuous or arrests it altogether. Pressure on a spot on the posterior surface of the organ just at the top of the intraventricular septum seems invariably to stop the heart-beat. Lifting the heart forwards in order to expose its posterior surface seems to have the same effect. Allowing the viscus to fall into position and stroking the surface, or applying gentle pressure on the ventricular wall or, if required, more vigorous massage will usually restart the beat. To assist in the process of suturing the viscus a stitch may be placed through the muscle near the apex, where the wall is thickest. If this takes a good hold it will not tear out, and when drawn upon it steadies the heart.

*Control of Bleeding.*—To control bleeding until sutures can be applied the pressure of the tip of the finger directly on the wound is best. Great care must be taken not to push the finger into the heart cavity. If this method does not suffice a stitch should be rapidly passed into each side of the wound and the ends crossed over without being secured. This will hold the edges together while the final approximating sutures are passed and tied. *Furious bleeding*—such as might follow



accidental tearing of the heart wall during manipulation—may be controlled by grasping and compressing the base of the heart between the fingers. This is known as the "Sauerbruch grip." Wounds should be sutured with 3/0 chronic catgut or fine silk. The stitches should be placed about a quarter of an inch from the margins of the wound and about the same distance apart. They should take a good hold of the cardiac muscle, but should not be so deep as to enter the cavity. It is not necessary to tie them tightly. If bleeding is not arrested one or two superficial sutures may also be used. Oozing should soon cease, but if

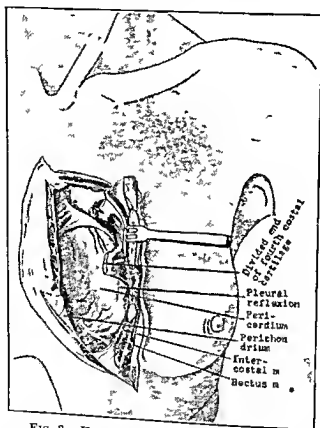


FIG 3—Exposure of the heart. The sixth rib is resected, the fifth, fourth and third costal cartilages are divided and retracted outwards along with the pleural reflection, and the pericardium is fully exposed. (Modified from *Textbook of Operative Surgery*, by Theodore Kocher.)

it does not pressure by the finger for a few moments will probably succeed. A piece of fresh muscle laid over the area will act as a haemostatic patch.

There are many records of successful interventions along these lines



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not only with immediate recovery but with complete restoration to health.

On August 6, 1918, René le Fort presented a report before the Academy of Medicine of Paris dealing with a patient on whom he had operated for the removal of a fragment of hand-grenade from the interior of the left ventricle, the patient recovering. At the same meeting le Fort stated that he had removed eleven foreign bodies from the heart in the course of nine operations. In two cases—the one just mentioned and another—the missiles were in the heart cavities. There was only one death in the series.

*The Question of Anaesthesia.*—In the grievously wounded and severely shocked it may suffice to employ local anaesthesia, and many interventions have been carried out aided by this means alone. The pericardium and the heart itself are said to be insensitive so that it is only a question of infiltration and block anaesthesia for the parietes. But, generally speaking, there is no contra-indication to a general anaesthetic skilfully used. Those who have been brought up in the belief that special anaesthetic apparatus is essential should realize that the many notable operative achievements of the last war were usually conducted under open ether anaesthesia.

### **Missiles Lodged in the Heart**

In the group of cases in which there is neither an open wound nor any question of cardiac tamponade the patient will usually make a good immediate recovery, and often without significant symptoms although a foreign body is lodged in the heart. It probably means that the missile has been of low velocity or that it has been, for instance, a spent bullet. There are a good many cases in which such foreign bodies have remained lodged in the heart for some years, apparently without mischief, and I might briefly refer to a case of my own in this connexion.

The patient was an officer, 32 years of age, who was wounded by a machine-gun bullet fired at a range of about 500 yards. There was a snowstorm at the time and the officer had his left hand up to keep the snow from his eyes, and as there was a through-and-through wound just above the elbow it is highly probable that the bullet that lodged in the heart first passed through the arm. In addition it traversed a notebook and a bundle of letters which he was carrying in his tunic pocket. The officer did not appear to have been very severely knocked out after the wound, and when I saw him at the base eighteen days later he was not in any way upset and was rather ashamed that he perforce arrived on a stretcher. The wound of entrance was through the front of the cardiac area and there was no exit. The radiograph showed the bullet in the region of the left ventricle. It was pulsating synchronously with the heart-beat, and in addition there was a whirling movement as if its apex was spinning about in the vortex of the blood stream. After due consideration I made an attempt to move the bullet, but without success. Now, twenty-four years after the



injury the patient remains perfectly well and is able to live a normal reasonably active life (*Lancet* October 19 1940)

In cases such as the above there is probably little or no haemorrhage from the wound in the heart. The missile may act as a plug as in a case recorded by A H Burgess (1934) or the firm contraction of the powerful muscular walls of the ventricles may suffice to stay bleeding. The ultimate fate of these missiles is important as a guide to their management. Though they may remain safely imprisoned in fibrous tissue indefinitely they may be the source of emboli or may themselves become dislodged and leave the cardiac cavity forming emboli in the main vessels. Scars associated with such foreign bodies have given way thus causing the sudden death of the victims. In fact there appears to be no end to the vagaries of these unwelcome visitors. The immediate symptoms are not always slight and there may be great cardiac irregularity and irritability and often dyspnoea. As a rule if these symptoms follow directly on the casualty they slowly disappear during a period of months especially if the environment of the patient is suitable. Much disability may be caused by fear of tragic consequences instilled into the patient's mind or the mere knowledge that the citadel of his well being is menaced. The fussy attitude of over zealous relatives and friends or even the medical attendant may be detrimental and is to be strongly deprecated. But in some cases with all the encouragement that hopefulness and the best will in the world can provide the patient may find that the least exertion brings on cardiac irritability or breathlessness and for that or other reasons the question of the removal of the foreign body may arise. In these circumstances there is no reason why the possible benefits of surgery need be denied. The matter will have long ceased to be an emergency and whatever investigations suggest themselves may be carried out at leisure and with proper deliberation. While I would be much opposed to the removal of such a foreign body at all costs I am strongly in favour of exploration for the missile may prove to be most fortunately placed for removal and if not the wise surgeon can always hold his hand.

### **Removing the Foreign Body**

In the actual intervention the Kocher approach ought to suffice and especially so if advantage is taken of the additional space which may be secured by removing the costal cartilages right up to the edge of the sternum or even cutting away part of the latter with rongeur forceps. The first problem is to find the foreign body and that often proves difficult. When the surgeon has finally decided where the cardiac wall



is to be incised sutures should be placed on each side of the proposed cut, and he must take care to see that these secure a good hold, as it is by their aid that bleeding will have to be temporarily arrested. The missile must be coaxed out rather than forcibly withdrawn, great care being exercised not to lacerate the heart wall. The defect in the heart must be closed by suture as already described. It is said (Decker) that the mortality from foreign bodies in the heart which are not interfered with is 20%, and that the mortality of surgical intervention is about the same, but it is highly probable that there are some unrecorded operative fatalities which would considerably increase the latter figure.

*Foreign Bodies in or about the Pericardium.*—These form an interesting group, for the pulsation of the heart is often communicated to them. In some cases they may be associated with sinuses or they may remain safely embedded for years without giving rise to symptoms. Further, they may be the cause of the same sort of disturbances as arise from the presence of foreign bodies in the heart itself. This knowledge justifies exploration in the hope that the missile may be found in a position from which it can be safely and easily removed. In dealing with these foreign bodies it will usually be best to open the pericardium as in the Kocher approach. Even when the foreign body is the cause of a sinus the cardiac movements may be communicated and the discharge lying in the mouth of the sinus may show pulsation. None the less, the proximity to the cardiac region need not deter the surgeon from dealing with such conditions according to established surgical practice.

It has been suggested that missiles in the heart or in the pericardium might be removed under the fluorescent screen, and this method has sometimes been practised by French surgeons. Either through a conveniently placed wound or a small incision suitable forceps are introduced into the pericardium with the idea that the foreign body may be seized and withdrawn under the guidance of the eye. While this method may be feasible with loose bodies or with those only very lightly attached, the consequences might be unfortunate if a missile in the heart wall that was acting as a plug was thus removed. The probabilities of failure would also seem to outweigh heavily the prospects of success. But the method has been successfully employed, and it has this virtue—that, if disaster is not precipitated, the other and more traditional methods can still be employed.

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# ANATOMY, PHYSIOLOGY, AND PATHOLOGY OF WOUNDS OF THE CHEST

By T. HOLMES SELIGER D.M. M.Ch. F.R.C.S.

In injury to the chest as also in the case of the head it is not so much the damage to the container as the damage to the contents that matters. Actual damage to the enclosed viscera may have a profoundly adverse effect on the respiratory and circulatory systems and to this may be added a series of secondary changes that result from the opening of the pleural cavity. These factors in themselves may be a grave menace to life but even if they are successfully countered the question of the later development of infection has to be considered. Consequently a chest wound offers problems that are not found in many other parts of the body where the extent and effect of the destruction can be more or less estimated immediately.

Before entering into any discussion of anatomy and physiology it is well to have one precept in mind and that is that the course and the effect of any missile after contact with the body are almost unpredictable. A well known surgeon once stated that he was quite prepared to believe anyone's story about the behaviour of any missile on any human frame and could add a few himself. The varying resistance of tissues the angles of impact and a whole host of factors make it imperative that no one should take the apparent track of a wound for granted when it comes to the question of diagnosis and treatment. Nor should it be forgotten that multiple injuries are only too common and that a small and apparently trivial wound may disastrously be overlooked in face of a more urgent and obvious lesion elsewhere.

## Some Relevant Anatomical Points

In considering the gross anatomy of the chest there are some quite elementary points that are not perhaps always fully appreciated. The first point that strikes one when looking at the thoracic cage stripped of its coverings is its tapering or cone shaped upper part. The squared appearance of the human torso depends on the shoulder girdle with its attached structures in the region of the shoulders the actual thorax is deeply placed and is well covered by muscle layers in contrast to the lower part where ribs are easily palpable and the form of the thorax is quite apparent. The practical application of this feature lies in the fact that a missile traversing the upper part of the chest will pass through thick muscle layers which tend to close on the track and prevent communication of the pleural sac with the open air. On the other hand



penetration through the lower part of the chest is apt to leave the pleural cavity open and produce the dangerous form of "sucking" wound.

Among other points that may be emphasized is the height to which the diaphragm rises into the chest. This "doming" upwards of the muscle infringes considerably on the long axis of the thorax and leaves at the periphery the deep costo-phrenic sinus, which, it should be noted, is deeper behind than before. A penetrating wound of the lowest chest will frequently puncture the diaphragm after injuring the lung fringe and produce varying lesions of the upper abdominal contents. The blood supply of the diaphragm is more extensive than might be supposed for such a thin sheet of muscle, and this should be remembered if incision through its fibres is practised.

A cross-section of the chest shows that the vertebral column projects far forward into the cavity, so that the distance between the sternum and the spine is relatively small (a matter of some 4 to 4½ inches), but on each side lies a large paravertebral gutter which accommodates much of the lung tissue. It is in these areas that fluid tends to accumulate in the pleural cavities, and that aspiration or drainage of the free pleural sac will be most effective.

The obliquity of the ribs is a feature that makes orientation and location in the chest much more difficult than if the thorax was a conveniently arranged system of transverse segments. A study of the normal antero-posterior radiograph illustrates the differences in level between the anterior ends of the ribs and their corresponding vertebrae. For example, the third costal cartilage lies in the same plane as the seventh thoracic vertebra, though clearly there will be individual variations according to whether the subject has a long flat chest or one of the barrel emphysematous type.

At this point it is not out of place to stress the importance of radiography, and indeed the absolute necessity for x-ray films in two planes, for the location of foreign bodies and other abnormalities. The ordinary antero-posterior view may reveal a foreign body lying close to the heart, but it requires a lateral film to show whether the abnormal shadow lies outside the chest or within it.

The anatomy of the ribs and intercostal spaces is important in view of the relationship of the associated vessels. The intercostal space is for all practical purposes a clear and safe area as regards the risk of haemorrhage—a feature that is taken advantage of in aspiration of the chest or when a trocar and cannula are inserted into the pleural cavity. The segmental vessels and nerve are under cover of the lower border of the corresponding rib, and will be injured only if the bone is broken. If it



is uncertain whether active intrathoracic haemorrhage is coming from lung and/or chest wall the fact that ribs are intact exonerates the intercostal vessels, but if they are fractured arterial bleeding is a possibility

### Effects of Various Types of Missile

As has already been stated, the effect of a penetrating wound of the chest is variable, but there are certain general tendencies which may be described briefly. A *bullet* produces a small punctured entry wound, and by virtue of its high velocity drills a clean hole with a minimum of surrounding tissue damage. If it passes through an intercostal space on both sides of the chest it does not make an unduly large exit wound. If, however, a rib is touched an explosive effect is produced and bone is shattered and driven onwards. This impact reduces the velocity and may turn the bullet sideways or even reverse it. The wound track is consequently more extensive and the damage to soft tissues correspondingly increased.

*Fragments of bomb* are jagged and acquire a tremendous spin, though their velocity is lower than that of a bullet. The effect on the tissues is extreme laceration even though the entry wound may in some instances be small. Pieces of cloth, dirt, and so on are apt to be carried in with the metal and are potential sources of infection, particularly as torn tissue and blood constitute a fertile soil for bacterial propagation. As against this last statement I must admit that most of the fragments that I have removed from air raid victims have proved sterile on culture. The lower velocity of this type of missile accounts for so many fragments being retained, and it is interesting to note how often their track ends subcutaneously. Presumably the elastic skin yields at what would otherwise have been the site of exit and does not break. I have seen the same effect inside the chest on several occasions when a fragment has punched a hole in the far side of the chest wall and recoiled within the meshes of the lung tissue, from which it was removed.

*Crush injuries* may be held to cover damage from falling masses of masonry, direct compression, and the like, and are often responsible for gross and fatal visceral damage without any penetrating wound. Ribs are commonly fractured, several adjacent ones giving way close to the posterior angle. If the bone also breaks anteriorly a whole section of chest wall becomes functionally loose and may be driven in—'stove in'—and may act paradoxically on respiration. Within the chest, lung may be avulsed from its root and rupture of the heart and great vessels be found.

The effects of "*blast*" have attained some prominence recently, but a



full description and an explanation of the findings have not yet been achieved. It would appear, however, that numerous small haemorrhages and effusions occur throughout the alveolar and interstitial lung tissue. Free blood in the air tubes accounts for haemoptysis and also for patches of atelectasis. The distribution of the lesions is erratic, but it is probable that the peripheral areas are most affected, as might be expected when the direct violence of the explosive wave is inflicted on the chest wall. Sometimes it is in the lung fringes that the lesion is well demonstrated, and this may be explained by nipping of the soft tissue between the lower ribs and the diaphragm, which is driven up by the impact on the abdominal wall.

### Physiological Considerations

The essential point of the normal physio-mechanics of the chest lies in the fact that two elastic lungs are pulling like evenly balanced springs on each side of the mediastinum. The lungs in turn are held out against the chest wall in a state of tension by the subatmospheric or "negative" pressure in the pleural sacs. If one pleural cavity is violated the underlying lung is released and recoils towards its point of fixation at the hilum. From this point a number of changes in the function of respiration take place.

With the formulation of a pneumothorax the balance of the lung pull on the mediastinum is upset and the heart becomes drawn towards the unaffected side, whose tractive force is undisturbed. Inspiration, with general expansion of the chest wall, increases the tension of the sound lung and draws the mediastinum even more towards itself. The result is that with each act of respiration the mediastinum swings to-and-fro or "flutters." The effect of inspiration is to draw air into the unaffected lung, but as it does so it rushes past the bifurcation of the trachea and abstracts some gases out of the collapsed lung. It also means that this lung becomes reduced in size. With expiration the reverse effect occurs and some gases are forced into the collapsed lung, which thus moves paradoxically on respiration.

The movement of gases from lung to lung—the "Pendelluft" of Brauer—results in a steady increase in the  $\text{CO}_2$  content and diminution of oxygen, with consequent inefficient and imperfect ventilation of the sound side. The sum of all these factors, if they occur to any marked extent, means that there is actual loss of ventilating surface by collapse of one lung, imperfect exchange of gases, and stimulation of the respiratory centre, besides the effects produced on the circulation by the to-and-fro movement of the heart and great vessels and interference with the venous return.



Puncture of the chest wall or lung may lead to an open pneumothorax but if the opening is not valvular little harm will result. But unfortunately in traumatic surgery it often happens that a ragged external wound through the parietes constitutes a valve and admits more air than can be expelled. Air bubbling and frothing through blood at the skin wound indicates that sucking wound that is potentially so dangerous to the respiratory economy. Within the free pleural sac air accumulates steadily—a feature that is made worse by bouts of coughing which are an almost inevitable concomitant of thoracic injury—and a state of intrathoracic pressure or tension is produced. *Tension pneumothorax* or pressure caused by a haemothorax is a common occurrence in thoracic surgery the mediastinum is pushed over and encroaches on the ventilation capacity of the opposite lung.

For recognition of this phenomenon there is a physical sign that is often overlooked—namely the position of the trachea in the neck. The tube is easily palpable in the suprasternal notch and any deviation is readily apparent. The sign is valuable since the apex beat and cardiac dullness are sometimes obscured by pleural fluid and are difficult to assess in a patient covered with dressings and bandages. The early recognition of a tension pneumothorax is of the utmost importance since its neglect may lead to death from direct mechanical embarrassment whereas its rapid relief could be obtained by putting a needle into the pleural cavity and letting the air escape.

It should also be remembered how tension phenomena can give rise to misleading signs and symptoms. The patient is cyanosed and distressed and has a persistent cough. Where fluid is present the chest is dull and on auscultation distant but definite bronchial breath sounds and rales are heard. The diagnosis of pneumonia may be made but the audible breath sounds are conducted through fluid from a lung completely collapsed on to its root and the rales are transmitted from the opposite side where the ineffective cough has been unable to expel mucus and secretions. There is no zone of partially collapsed lung to act as a damper between the air current in the bronchi and the chest wall to which the stethoscope is applied. To make an error in diagnosis as described may seem unnecessary but in a very distressed and mutilated patient it is not always easy to practise the thorough and complete examination which would lead to the recognition of the true state of affairs. One can only emphasize the importance of remembering the possibility of tension occurring and deciding whether or not the trachea is in the midline.



### **Subcutaneous Emphysema**

This is a common accompaniment of thoracic injury. The air usually comes from the torn lung and is expelled through a breach in the chest wall, but does not escape adequately through an external skin wound even if one is present. The axilla and clavicular fossae demonstrate the typical crackling sensation, and in a severe case the whole head and neck may blow up, making the patient unrecognizable and the eyelids so swollen that he is unable to see. The condition is always more alarming than dangerous, and when it occurs in a crush injury without a surface wound it suggests damage to lung by broken rib fragments.

### **Haemothorax**

The possible origins of blood in the pleural cavity are threefold: the intercostal or internal mammary vessels may be torn, pulmonary vessels may be ruptured, or the heart and great vessels may have been damaged. Clinically it is important to decide whether the bleeding is active or whether it has undergone spontaneous arrest. Section of an intercostal artery is likely to lead to uncontrolled haemorrhage and may therefore require urgent attention; but pulmonary haemorrhage, unless rapidly fatal, tends to check itself. The reason for this latter lies in a balance between two groups of opposing factors. On the one hand, vessels in the lung have a wide lumen and the capacity of the pleural sac to receive blood is considerable; but as against these features there are the potent influences of the relatively low pressure in the pulmonary circulation and the tendency of the lung to retract and so reduce the actual size of the wound in itself. To put it in another way, blood and air in the pleural sac form a pad which acts against the bleeding area. A haemothorax of several pints capacity is not incompatible with life, though prompt blood transfusions have certainly saved many lives.

Blood in a haemothorax has one most unusual character in that it tends to remain fluid in a large number of cases. Infection and tissue laceration may produce massive clotting, but in many instances the effusion shows little if any clot and can be aspirated efficiently through a needle. I have on a number of occasions estimated the haemoglobin and fibrinogen content of both the circulating and the free pleural blood within a few hours of injury. The haemothorax fluid shows on an average a reduction of 35 to 50% haemoglobin and an almost complete absence of fibrinogen. The inference is that the movements of the heart and lungs have whipped up and defibrinated the blood as it wells into the pleural cavity. To account for the reduced haemoglobin figure it



is suggested that the blood is diluted by a serous effusion poured out from the pleural endothelium in response to the irritation by blood. The amount of clot, if any should be present, is so small that it seems improbable that a concentration of red cells in it would account for the low haemoglobin figure.

### **Massive Collapse**

Massive collapse or pulmonary atelectasis is a feature that is quite often encountered, particularly with a crush type of injury. At first sight it may seem difficult to understand how an injury to one side of the chest can cause collapse on the opposite side, but the present conception of atelectasis as being basically caused by obstruction to a bronchus makes the explanation fairly straightforward. Blood or mucus in the bronchial tree may not be removed effectively when the expulsive cough reflex is reduced by shock or pain. The foreign matter obstructs an air tube and as a result of this the gases distal to the block are rapidly absorbed into the blood stream. The alveoli become emptied and their walls fall together so that the affected area of lung is represented by a wedge of bronchi, vessels, and airless connective tissue. This elastic mass now affects the surrounding structures and draws them toward itself. The mediastinum is pulled over, the diaphragm elevated, and the chest wall retracted, and the adjacent lung develops compensatory emphysema. If the atelectatic area fails to re-expand, as it does in some cases, the pull of the elastic fibres is finally directed on the only structures which are left for it to affect—the enclosed bronchial elements. In the early stages the cartilaginous bronchial walls tend to resist the external traction, but the continued centrifugal pull finally results in their stretching and becoming dilated. In short, in any case of persistent collapse bronchiectasis will inevitably follow, and it is a question of later secondary infection which determines whether or not the classical signs of infective bronchiectasis will develop.

### **Pathological Changes**

The pathological changes in traumatized lung are very much what would be expected, laceration and haematoma formation being the principal features. The extensive blood supply of the lung accounts for the fact that many badly torn fragments remain viable though their inability to later infection is considerable. A haematoma of the lung presents as a tense firm swelling of rubber like consistence and of a purple or violet colour, with the visceral pleura stretched almost to breaking point over its surface. Extravasation into alveoli produces a condition of con



solidation which is demonstrated clinically by stained sputum, which later becomes purulent as the condition resolves. The detailed effects of infection on the lungs and pleura will not be discussed here, though their role in the subsequent fate of the patient is clearly of the utmost importance.

### **Distant Reflex Complications of Chest Injuries**

These complications are often considerable though some of the effects may be attributed to damage inflicted elsewhere in the body. There are, however, certain features associated with what appears to be chest injury alone, and of these retention of urine is the most common and most easily remedied. Acute dilatation of the stomach is apt to be overlooked in its early stages and, if untreated, may cause considerable and serious trouble. Among these abdominal complications may also be mentioned "blast," in which multiple and diffuse haemorrhages in the mesentery and under the bowel peritoneum may result in a fatal peritonitis; I have encountered two such cases accompanying a penetrating wound of the chest.



# CLOSED WOUNDS OF THE CHEST, AND THE PHYSICIAN'S PLACE IN A CHEST TEAM

By J A NIXON CMC MD FRCP

Changes in climate the nature of the soil, the character of weapons and missiles render the aspect of gunshot wounds of the chest exceedingly variable. In the South African War it was decided that chest wounds were best left to the natural processes of cure. In the war of 1914-18 sepsis was so frequent in all varieties of chest wound that by 1916 Duval of the French Army and Gask of the British Army first began to apply the general rules of surgery to lung wounds. In July, 1917 a meeting of consulting surgeons and physicians drew up a memorandum which was communicated as a guide to all medical units.

## A Guide for Medical Units

Briefly the following rules were laid down

- 1 An open pneumothorax should be temporarily closed by suture at the earliest opportunity either at the field ambulance or CCS. If suturing is impossible the wound should be packed and strapped to render it airtight.
- 2 Extensive parietal wounds including the above should be treated as any other large wound the comminuted rib fragments removed.
- 3 A large foreign body shown by radiographs to be accessible should be removed, haemothorax evacuated and the chest closed. Bullets or small fragments may be left.
- 4 Any large haemothorax attended by persistent respiratory distress should be aspirated; this is best done after a lapse of forty-eight hours.
- 5 Gross infections may be treated by rib resection and drainage. Mild infection may be closed after thorough cleansing of the pleural cavity.
- 6 Set operations should not be performed until initial collapse has passed off.
- 7 Always close a wound of the diaphragm discovered at a thoracotomy.
- 8 Any case subjected to open thoracotomy must be retained for ten days after operation.
- 9 Reliable x-ray plant and immediate access to a pathological laboratory are essential to successful chest surgery.

These rules made a great change in the number of cases left to expectant treatment. Gask estimated that perhaps 25% of cases needed surgical treatment in the first twenty-four hours, even through and through rifle bullet wounds often become septic. Captain Mann of No. 3 Canadian CCS (with whom I worked for a short time in 1917) noted that septic empyemata were not more common with retained missiles than with through and through wounds, and that fragments of high explosive missiles showed only a slighter tendency to become septic than did rifle bullets. Of cases with retained foreign bodies (10% bullet 90% shell)



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16% developed septic haemothorax at the C.C.S. (11% bullet, 89% shell). Of cases without retained foreign bodies (39.5% bullet, 60.5% shell) 21% developed septic haemothorax (20% bullet, 80% shell). The determining factor seemed to be the character of the wound rather than the nature of the missile. Injuries to ribs and laceration of soft parts were mainly responsible for the production of sepsis.

So it came about that the proportion of cases that would from choice (not military necessity) be left to expectant treatment was small. The idea that "closed wounds" as a whole class do not need surgery is dangerous. This is especially true of "stove-in chests" with several ribs smashed and driven in without any penetrating wound. These are veritable "closed wounds," but it was universally agreed that they required immediate operation.

During the summer of 1917 Major Lockwood (of Toronto) and I had the good fortune to be so stationed at Zuydcoote, near Dunkirk, that we received our chest cases direct from the line. They came to us at No. 36 C.C.S. without stopping at a field ambulance. The Passchendaele battle did not affect us, except that no ambulance trains could be spared to take our cases to the base, so we kept our patients through to convalescence. In parenthesis I may remark that we shared the vast sanatorium at Zuydcoote with the French Mobile Surgical Unit 21, of which Prof. Duval was the chief surgeon. We worked there from August to November, 1917. The total number of "G.S.W. chest" admitted was 168; operations were performed on 82, and non-operated cases amounted to 86. Of the non-operated cases 9 were brought in dead, 21 died within a few hours of admission, yet 55 survived. It appears that we refrained deliberately from operation in only 56 cases. As I look through the fatal non-operated cases I think No. 48 is the only one upon which we decided of free choice not to operate. The results of this group of cases turned the scale in favour of early operation rather than early evacuation to the base.

I have one other set of figures of Lockwood's and mine. In September, 1916, 203 cases were admitted to a special chest ward at Heilly. Of these only 16 died in the C.C.S., but this low death rate is partly explained by the fact that abdomino-thoracic injuries were taken into surgical wards and classified separately. I do not know what was the after-history of the 187 cases evacuated to the base; but of the 168 cases at Zuydcoote 113 lived and were discharged by us convalescent. Lockwood noted in his paper that the figures showed a high percentage of recoveries in cases that previously showed a mortality of nearly 100%.

I lay stress on this experience because it shows how few cases a



physician will choose to treat expectantly. Perhaps the prophylactic use of sulphanilamide may justify a change in practice.

### Classification of Cases

It comes to this then there were very few GSW chest that, in the climate and soil conditions of France and Flanders, a physician would choose for expectant treatment. But circumstances may compel expectant treatment—for example the absence of surgical facilities or, even with these facilities the absence of radiographic facilities, or the patient may be unfit for operation owing to the severity of the intra-thoracic injuries the severity of external or complicating wounds loss of blood or collapse or shock due to cold or transport. Allowing however for such considerations there remain two classes of closed wound which the physician may be allowed to look after (1) the cases in which no operation has been deemed necessary and the patient's condition is good (2) the cases upon which operation has been performed and in which the surgeon has closed the chest. No physician without experience of war surgery of chest wounds is competent to select cases for Group 1.

### Early Aspiration

The whole plan of treatment of closed wounds may be summarized in a short sentence. No fluid whether blood serum or pus must be allowed to collect in the chest. Early and frequent aspiration must be resorted to whether thoracotomy has been performed or not.

As a rule it is injudicious to aspirate for either pneumothorax or haemothorax immediately after the wounding. Occasionally it is obvious from the urgency of the dyspnoea that relief might be obtained by immediate aspiration. Sometimes this becomes evident after resuscitation has been tried without success or with only partial success. The patient recovers partially from his shock and as he recovers dyspnoea which is often absent while the respirations are feeble and shallow begins to show itself. It is important to recognize that urgent dyspnoea with cyanosis soon after wounding is more pronounced in cases of extensive collapse or deflation of the lung without much haemothorax or pneumothorax than in cases in which the latter conditions are unaccompanied by collapse of the relatively uninjured lungs. A useful point in diagnosis is that haemothorax or pneumothorax pushes the heart away whereas collapsed lung pulls it.

The post operative aspiration of a chest must conform to the one rule that no fluid must be allowed to collect in the pleural cavity. Looking



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back at Lockwood's cases I find it was the rule that a chest closed at operation was explored eighteen hours later. Exploration was usually repeated several times. Cultures were made, but the discovery of pyogenic organisms or pus did not mean that the chest was reopened and drained. We always tried repeated aspiration. Lockwood's comment on this point was: "The rapid recovery by aspiration from an empyema infected by aerobes and anaerobes demonstrates that repeated aspiration should be resorted to before considering resection and drainage. The mortality of the latter operation in chest wounds at C.C.S. is nearly 50%." Lockwood's rules should be adhered to.

"Chest cases should be nursed in the open air if possible. Aspiration is carried out as a routine eighteen hours after operation and at the end of the third day. Exploration of the chest is performed at frequent intervals whenever an accumulation of even small quantities of fluid is suspected, and fluid, if found, is removed by aspiration. Fluid must not be allowed to collect after operation. Physical signs are misleading, and nothing but repeated use of the exploring syringe and aspirator, aided by x-ray examination, will keep a chest safely emptied of fluid. Non-operated cases should be treated precisely as post-operative cases."

It is noteworthy that open drainage did not come into his scheme.

We did not recognize in the war of 1914-18 a separate class of "blast injuries" of the lung such as has been described amongst the air-raid casualties of the present war, and I have not seen enough examples to express any opinion about such injuries. It must be realized that the victims of air raids reach hospital alive with injuries to which a soldier succumbs on the battlefield, and we know that 50% of all chest wounds resulted in death on the battlefield in the last war. No one knows whether "blast injuries" contributed to these deaths.

### **The Physician's Place in a Chest Team**

Now I want to say something about the physician's place in a chest team, because there is always a definite place for a physician. One of his first duties is to decide as to the intrathoracic injuries in the following way: Is there a sufficient degree of pneumothorax, haemothorax, collapse of lung, laceration of haematoma of lung, injury to heart, pericardium, or great vessels, injury to diaphragm and abdominal viscera, or injury to vertebrae or spinal cord to account for the severity of the symptoms?

Radioscopy and radiography are indispensable in order to reach a correct conclusion on these points. If the patient is unfit to undergo immediate x-ray examination the decision is easier. He is unfit for any immediate operation save one of the following: immediate and rapid



operation for the arrest of visible haemorrhage from the chest wall or thorax arrest of haemorrhage from coexisting wounds aspiration for relief of pneumothorax (usually valve pneumothorax), aspiration for relief of haemothorax temporary closure of open pneumothorax

Duval pointed out the immense value of blood pressure observations in the differentiation of shock from haemorrhage The patient must be kept warm and every half hour the blood pressure be gauged by the sphygmomanometer In cases of pulmonary haemorrhage great care must be taken not to lower the head and not to administer subcutaneous or intravenous injections If the blood pressure progressively falls operation is indicated as haemorrhage is outweighing shock It must be realized that a patient with a simple through and through wound or one with a small missile retained should not be profoundly collapsed or in great respiratory distress after being kept warm and at rest for an hour or two If at the end of this time the condition has not improved the following possible causes must be considered in addition to the intrathoracic lesions just mentioned haemorrhage severe parietal and external thoracic injuries diaphragmatic and abdominal injuries and multiple wounds other than abdomino thoracic

### **Haemorrhage**

This may have been very large in amount and there may still be active bleeding As a rule with closed thorax the amount of intrathoracic haemorrhage will not of itself be enough to produce severe shock When there is an open thorax the estimated size of the haemothorax is no guide to the quantity of blood lost as the greater part of the bleeding may have been external In such a case physical examination is of little assistance beyond determining that there is an open thorax and that the patient is suffering from loss of blood If the missile has been retained it is of the greatest importance to locate it accurately by radiographs Signs of increasing effusion after twenty four to thirty six hours are scarcely ever due to active haemorrhage Lockwood and I saw only 5 cases of recurrent haemorrhage

### **Severe Parietal and External Thoracic Injuries**

Comminuted fractures of ribs scapula or sternum produce the gravest symptoms even in the absence of severe intrathoracic injuries It is of the utmost importance in such cases to determine the extent of the intrathoracic or pulmonary injury Physical examination by auscultation and percussion is difficult to perform and more difficult to interpret It will give little information beyond establishing the presence or absence



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of haemothorax or pneumothorax. But it is essential for the surgeon to know beforehand whether this operation should be limited to the parietes or should extend to the interior of the thorax. As a general rule; if the entrance wound is small and clean and there is no comminution of bone, whilst the extensive bone injury is confined to the exit wound, there will be no in-driven fragments, and the operation may be limited to the parietes. But if the entrance wound is large, if there are in-driven fragments of bone or pieces of clothing, and especially if a large missile is retained, the operation must extend to the interior of the chest.

### **Associated Injuries**

Careful attention has always to be paid to injuries other than purely thoracic which may have been caused by the missile or missiles which have struck the chest, particularly injuries of the diaphragm and abdominal viscera. A prompt decision must be made as to whether there is sufficient thoracic injury to produce the symptoms or whether the thoracic injury may be ignored and a further explanation be looked for below the diaphragm. To the surgeon a definite and reliable opinion expressed by the physician that the intrathoracic injury is negligible is of great assistance. In order to form a definite opinion in such a case, physical examination of the chest becomes more important than in the class of case previously considered. If the heart is not displaced; if there is no great degree of surgical emphysema; if there is no large amount of air or fluid in the chest; but, above all, if there is a fair degree of air entry into the lungs, it may be assumed that, although the missile has entered the chest, the grave lesion exists elsewhere. In a through-and-through wound the track of the missile may make it obvious that no important structure has intervened; failing this, radiographs will be required unless the presence of an abdominal injury is made clear by other signs and symptoms. Abdominal rigidity and immobility are not by themselves clear indications of abdominal injury; these signs are often present in pure chest injuries. Increased dullness in the spleen area, haematuria, the presence of dullness in the flanks, localized tenderness and pain in the abdomen, the peculiar "catchy" breathing suggestive of diaphragmatic injury, and hiccups are signs that should be noted and interpreted as indicating injuries below the diaphragm.

### **Spinal Injuries and Multiple Wounds**

Spinal injuries demand recognition, and not merely those which involve the actual spinal cord. Injuries to the body or processes of vertebrae may cause the gravest symptoms and present very puzzling



features Excessive pain, radiating very irregularly, is constantly met with in injuries of the vertebral bodies, and resembles the intense and erratic pain due to erosion of the vertebrae by aneurysm Profound collapse which resists all efforts at resuscitation is often seen in spinal injuries, even when the cord is undamaged

Apart from the associated injuries which the missile entering the chest may have produced, there may be other wounds that make it difficult to decide whether the patient's serious condition is attributable mainly to the chest wound or not Here, again, if there is fair air entry into the lungs, the intrathoracic injury may be put on one side A patient with one lung expanding well should not be greatly distressed even though the other lung is completely out of action, provided some hours have elapsed to allow him to adjust himself to his new conditions, and provided he has been kept at rest



## STAB WOUNDS OF CHEST WALL AND LUNGS

By ALEX STEWARD, M.D.

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No class of wounds, unless it be in a few centers of the brain, involves the essential physiologic processes of the body more rapidly than wounds of the chest. In addition to the rapid physiological changes which must be met, many pathologic sequelae may be expected. No class of wounds requires more accurate judgment at onset or more persistent care during its course.

Injuries and wounds of the chest have been classified in several ways. Lilienthal<sup>1</sup> divides them into superficial, penetrating and perforating, the last two classes being differentiated only by degree. A simpler classification is given by Cole<sup>2</sup> into external and internal chest injuries, while Bigger<sup>3</sup> calls them perforating and nonperforating. A similarly explicit description may be made of superficial wounds which involve layers of the thoracic wall to the parietal pleura, and deep wounds which extend through the parietal pleura to varying depths.

An analysis of the type of wound upon which this discussion is based may be estimated from the figures for the thoracic service in a two hundred sixty bed city and county hospital for one year and will serve as an average cross section of these injuries. The wounds are similar to those discussed by Elkin.<sup>4</sup> Two hundred ninety-seven patients with chest wounds were received in the emergency room. General figures showed eighty-eight to be white and two hundred nine to be colored; two hundred four were males and seventy-one females; twenty-two were dead on arrival. The causative agents of the chest wounds were: nineteen from automobile accidents, eighteen from gunshot wounds, seven from industrial injuries or minor accidents about the home or farm. The remainder of the two hundred fifty-three wounds were hand inflicted apparently with homicidal intent. It is with this last group that we are interested. Of these chest injuries, ninety-four were committed with knives, fifty-seven with ice picks, twenty-one with razors, one with a hatchet and in fifty-eight cases the patient either did not know or was unwilling to tell what weapon was used. These figures are summarized in Figure 1. Fortunately for the hospital, the majority of the chest wounds are superficial in type, and of two hundred fifty-three stab wound cases, only one hundred four were admitted to the wards.

Among the Negroes, (the two to one offenders) the ice pick is a favorite weapon; it costs five cents, is not conspicuous, looks bad when drawn and with a metal handle may easily be thrown a hundred or more



fect when it is time for flight The switch or spring released knife, the blade of which varies from four to six inches is a more expensive favorite A frog is a single bladed knife, three and one half to five inches whose pin is oiled and spring filed so that it can often be opened on the throw almost as rapidly as a switch

Peculiarly very few bayonet wounds of the chest were seen in the hospitals during the last war The reasons given for this are first that the wounds were so severe that the victim failed to survive the trip second that the armies were taught to lunge for the abdomen so that the bayonet would not be caught in the ribs and third in case the bayonet was difficult to withdraw to shoot it loose During the Civil War with much hand to hand fighting there were reported in the Federal Records by Barnes only thirty eight sabre and bayonet wounds in a total of 216 712 wounded

	Total	White	Colored	
Automobile	19	11	8	
Quarrel	10	10	0	
Intoxication	7	5	2	
Hand inflicted				Mortality
Blow on forehead	27	4	11	10 or 33% and 21% for the admitted cases
Knife	24	42	54	
Ice pick	17	9	40	
Saber	21	2	12	
Bayonet	1	0	1	
Others	30	3	11	
Total	127	68	108	



## *Stab Wounds of Chest Wall and Lungs*

slashed by an irate husband or jealous wife. Morphine and reassurance may quickly cure what appeared to be an exsanguinated patient, and an adequate pulse pressure confirm the cure. In examination of the chest, it must be remembered that a peripheral injury will cause a degree of splinting commensurate with the pain, and decreased expansion and respiratory sounds. Also, a definite atelectasis of a portion of the lung may be produced by an external blow.

The superficial wound should be carefully examined and, contrary to some authors (Head,<sup>6</sup> Davis,<sup>7</sup> and Everett<sup>8</sup>), explored, débrided and accurate hemostasis established. More care than is usual in soft tissue wounds should be used. The attendant dangers of any soft tissue wound—hematomas and infection—are present, but the danger of a hematoma or infection following a small opening inward through the constantly moving thoracic wall is the reason for most meticulous surgery. The usual patient with a stab wound has a dirty body and clothing and requires careful débridement.

The external bleeding from intercostal vessels is particularly disturbing and must be stopped. Instances of extrapleural but intrathoracic hematoma with marked exsanguination have been reported. The intercostal vessels themselves are usually well protected, particularly in the adult's lower chest, by lying in a groove on the inferior and inner aspect of the ribs. If the bleeding point is not seen by simply spreading the wound edges, strong retraction of the intercostal and the serratus muscles may bring the severed ends of the vessels into view. Should

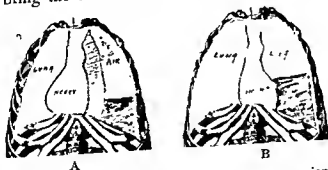


FIG. 2.—A, diagram of hemopneumothorax with compression of lung and displacement of heart from interpleural aid and basal collection of blood. B, diagram of intrapulmonary type of bleeding with little heart displacement.

this fail, a sub-pleural suture may be passed around the entire rib above and below the site of the bleeding. As a last resort, a section of the rib must be removed without hesitation.

After closing the superficial wound, it is well to strap that region of the chest thoroughly. The strapping and immobilization are done



for the patient's comfort and in an effort to prevent delayed bleeding, which is aided by the rhythmic movements of the chest.

Because many of these wounds are contracted in tetanus infected localities and are often puncture wounds in nature, the use of tetanus antitoxin should be made routine.

Deep wounds extend through the parietal pleural and the difficulties manifoldly increase. Should the external pleura alone be injured, there is the possibility of a pneumothorax. The amount of air will depend on the size of the opening through layers—the sucking wound. With the sucking in of air, blood from the external layers of the wound will also be drawn into the pleural space producing a hemopneumothorax. If the wound extends to the lung tissue, we have the possibility of both an internal pneumothorax and an external hemopneumothorax (Fig 2A).

With the formation of the pneumothorax there is collapse of the lung. The extent of collapse will vary with the size of the openings and the presence of pleural adhesions. Graham (quoted by Bigger), has shown experimentally that if the size of the external opening equals the cross section of the bronchus, there will be an adjustment of pressure. However, the soft tissue may make a trap door which closes during expiration and the internal pressure will rapidly increase. This is particularly true when the lung is torn and the patient is coughing. The intrathoracic pressure of the cough is estimated to be as high as 87 mm of mercury, by Starling,<sup>9</sup> and under such pressure considerable air is forced through even a small lung opening into the pleural space. Should adhesions attach the lung to the chest wall, these may be torn loose, giving a second internal opening or a secondary hemorrhage.

The rapid collapse of the lung and its compression against the mediastinum causes more or less cardiac displacement. The degree of displacement is modified by previous adhesions of the lung to the chest wall and mediastinal fixation. If there be little heart displacement, the compression of the lung against the thin veins and auricles may cause circulatory embarrassment. When the mediastinum is entirely without fixation, the heart may be markedly displaced and swing laterally from the great vessels with each respiration—a condition long recognized in thoracic work as pendulum shock.

Not only is the heart subjected to displacement and embarrassment but in the presence of extensive pneumothorax the remaining lung is frequently robbed of an appreciable portion of its air. With the shallow respiration resulting from shock and pain a portion of the air in the active lung is shifted back and forth into the dead space of the opposite



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bronchial tree. The Germans have called this phenomenon "pendle luft," and these patients may actually die from lack of oxygen.

The first treatment in deep wounds is to stop the sucking in of air. This may be accomplished by a few sutures, or if a large wound, by a temporary rubber dam placed over the opening to act as an externally discharging valve. The wound should be repaired as quickly as the patient's condition will permit, under an anesthesia during which a positive pressure may be maintained.

To prepare for surgery, the shock in these patients must be combatted. Morphine, heat and aspiration of the pneumothorax by a needle or valve are the best procedures. Intravenous solutions must be used with the greatest caution. This fact has been emphasized in complications following thoracoplasties, but has not been sufficiently applied to traumatic emergencies. If the patient is suffering from systemic shock, incident to trauma in which the pneumothorax is a minor part, intravenous support of the circulation may and should be used. If the condition is the result of cardiac embarrassment from lung compression and mediastinal displacement, increasing the burden on an already embarrassed right heart may result tragically. Intravenous solutions enter the right heart first, right ventricular pressure at best is only 15 to 20 mm. of mercury, and in the presence of traumatic pneumothorax the veins and right auricle are often struggling against air pressure greater than they can produce.

The immediate needs for severe pneumothorax are oxygen, which at times is supplied by the longer, deeper respirations following moderate doses of morphine, or directly by oxygen with a nasal tube, and a release of the collapsed lung from the high intrapleural pressure. The pleural pressure may be released through an intercostal needle, any of the metal valves designed for this purpose, or a tube, inserted intercostally, with a slit finger cot tied over the end acting as a valve. The finger cot valve is less cumbersome than an outlet under water although the suction with the tube under water may be increased by lowering the receptacle. Of the three methods, the catheter inserted intercostally through a trocar and a slit finger cot tied about the distal end, allows a rapid release of pressure in the emergency room and its action can be easily observed.

Should the pneumothorax be complicated by bleeding, the fundamental compression of the lung remains the same but the treatment must be more active. Bleeding into the pleural cavity may be from the thoracic wall inward or from the lung or both. If from the thoracic wall, the intercostal vessels are the great offenders and must be ligated



as soon as the patient's condition allows. Should the bleeding be from the lung there are two sources, the bronchial arteries or the pulmonary vessels. Little attention in traumatic chest condition has been given the dual blood supply of the lung, although Bettman<sup>10</sup> has called attention to the pathological differences in the two circulations. Should the periphery of the lung and the pulmonary vessels alone be involved, there will usually be found a moderate amount of blood and a moderate pneumothorax. Both of these tend to compress the resilient lung tissue, to close the opening and to check the hemorrhage. The physical findings of the hyperresonance, basal flatness and diminished or absent breath sounds are typical of the condition.

Because of the original low pressure of the pulmonary vessels and the early branching the reduction to capillary pressure is rapid. The increased pressure of the pneumothorax will cause hemostasis in the moderate internal type of wound. If there is no evidence of cardiac embarrassment or signs of increasing hemorrhage, the patient may be treated generally until about seventy two hours has elapsed. This length of time allows small vessels to clot and gives an idea of the presence of primary contamination. An estimation of the amount of blood is attempted from the x ray. In reviewing the films, it is well to remember that blood has a tendency to spread over the pleura and give an exaggerated picture (Wood and Eloesser<sup>11</sup>). Also, the pleura rapidly dilutes the blood with serous exudate to increase the fluid as compared with the first picture.

Following war experience, Morelli and Lilienthal advocated aspirating blood from the pleural cavity and replacing it with air. The method was met with considerable opposition by those of the profession who feared infection. While a portion (about 8 per cent) of all hemothorax cases will become infected, the majority of observers (Sontag,<sup>12</sup> Boland<sup>13</sup> Sandison<sup>14</sup> and Miller<sup>15</sup>) advocate aspiration and air replacement because (1) series of cases fail to show a higher incidence of infection (2) hospitalization is shortened, and (3) there is less residual pleural thickening and atelectasis of the lung tissue.

Later complications of lung injuries are empyema and abscesses with their long attendant difficulties and acute respiratory infection. These must be treated as the case demands.

When a bronchial artery of medium size is severed, a very serious problem is presented. The bronchial arteries arising from the aorta receive the systemic pressure of the left ventricle. They accompany the main bronchi and their injury usually involves the bronchus. In these cases the bleeding is intrapulmonary. Gurgling bronchial rales at first



heard below the level of the wound are rapidly silenced as the alveolae are filled with blood. The percussion note is flat. There is usually little cardiac embarrassment or displacement. As the level of the blood rises into the bronchi immediately above the injury, coughing produces small amounts of bright blood. Aspiration usually obtains only a few cc. of blood. However, should the rent in the peripheral lung tissue be large, the blood may find its way directly into the pleural cavity. In such a case aspiration of the blood and compression pneumothorax with air may be utilized. The patient is in no condition for exploration or lobectomy. When exsanguination is imminent and donors not available, auto-transfusion of the aspirated blood directly into the median vein may be used. A 50 cc. syringe with an outlet stop cock, glass connections and rubber tubing make a satisfactory apparatus. The side opening of the stop cock is utilized for transfusion and air replacement.

The chest wound with bronchial artery bleeding and bronchial damage is the most difficult type and the least satisfactorily handled. With the lung tissue filled with blood, interpleural pressure with pneumothorax has little effect on the solidly filled organ as it is impossible to inject sufficient air pressure to stop any except a small bronchial vessel. Intravenous therapy will increase the blood pressure and the bleeding. Exploration for the bleeding vessel is impractical. Phrenicotomy, with the weight of the blood on the diaphragm, may cause its descent and increase the intrapleural area. Supportive measures and allowing the rise of the blood level within the lung tissue to compress the vessel is the best procedure.

If the bronchial vessel is small and only part of a lung involved, the patient may respond to the treatment of "masterful inactivity." Very slow resolution of the blood with a low (100°), constant temperature for about eight days may result. Six months later a narrowed atelatic shadow, slight diaphragm rise and emphysema of the lung above may be the only residua.

Should the intrapulmonary bleeding be massive (approximately two-thirds of a lung), recovery from the bleeding will be followed by a disappointing series of complications. A gangrene of the alveolar tissue results in a sepsis. This is usually discernible at about the fifth to sixth day by a septic temperature, and leucocyte rise. Drainage, closed or open, has no appreciable results. Radical rib resection, removing large quantities of gangrenous material and packing and irrigating with various antiseptics, produce no results other than a bronchial fistula and the patient grows slowly more septic. For these reasons, I advocate lobectomy in the intrapulmonary type of bleeding at the first signs of



sepsis A diagram of the simple hemopneumothorax as compared with the intrapulmonary type of bleeding is seen in Figure 2

## Conclusions

- 1 Care must be taken in examining and repairing superficial chest wounds
- 2 The immediate closure of deep chest wounds should be done and aspiration or valve control of internal pressure should be used
- 3 The mistaking of systemic shock for right heart embarrassment and the danger in using intravenous solutions in the presence of increased intrapleural pressure is emphasized
- 4 There is a difference in treatment and results of wounds involving the pulmonary and those involving the bronchial vessels
- 5 Lobectomy or pneumectomy should be used in massive intrapulmonary hemorrhage at the first signs of sepsis

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## OUTLINE OF TREATMENT FOR SEVERE WAR WOUNDS OF THE CHEST

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Wounds of the chest related to bombing offer no special surgical problem because the devastating effects of hurled fragments of glass or stone are analogous to those of flying fragments of high explosives. Although the character of chest wounds thus remains essentially unchanged from that of the first World War, considerable difference in treatment should be anticipated because of the advances in thoracic surgery in the intervening two decades. The advances have been in three principal directions: (1) a better understanding of cardiorespiratory physiology, (2) positive pressure anesthesia, particularly with the newer anesthetics and (3) the technic of removal of large sections of pulmonary tissue. In this outline of management of thoracic wounds I propose to indicate the part which I believe these advances should play.

As in other serious wounds, the effects of shock and hemorrhage often are to be combatted in the initial phase. There are two features inherent in all serious thoracic wounds which create special problems: (1) the agitation of a rigid yet constantly moving bony cage, and (2) the likelihood of interference with the function of the heart or the lung, or both. Significant effects of the severer injuries can be briefly enumerated: (1) air in the pleural space with or without blood, (2) bleeding into the pleural space which tends to continue if the lung collapses, (3) sucking wound with increasing intrapleural tension and mediastinal shift and (4) bleeding into the pericardial sac and cardiac tamponade.

Diagnostic questions are here omitted yet emphasis should be placed in season and out of season on the fact that grave damage may result from an apparently insignificant penetration or, put in another way, an insignificant penetration has usually inflicted grave damage if shock has been induced.

The surgical management of a serious thoracic wound should be related to the time and place of first treatment, the urgency of the case and the availability of special personnel and equipment. General treatment will not be considered. The primary requirements for the local lesion are: (1) morphine, regardless of a possible untoward effect on cough or respiration, (2) for a sucking wound, tight packing and strapping and (3) for hemorrhage from the thoracic parietes, tight packing of the entire tract in the chest wall. Incomplete emergency operations, such as the suturing without debridement of a sucking wound,



are to be deplored. If the patient is suffering from tension pneumothorax after emergency packing of the wound, the trapped air should be at least partially withdrawn by any available means. When, however, tension pneumothorax is due to a laceration of the lung, resort must be had to a continuous evacuation of the air. There are two excellent methods for this purpose: closed drainage under water into a bottle situated considerably below the level of the chest or, especially for a patient to be transported, an intercostal tube with attached flapper valve as devised by Lilienthal.

An urgent condition which calls for immediate surgery whenever possible is cardiac tamponade due to a penetrating wound of the heart. In addition to the picture of shock its evolution is characterized by a progressively smaller pulse with corresponding drop in the blood pressure, distended veins in the neck and a silent heart. The absence of cardiac pulsation which is the essential operative indication, can be established unequivocally only by fluoroscopic examination. Lacking such confirmation and in the absence of specially trained medical personnel nonoperative treatment is probably safer.

Indeed specially trained personnel (surgeon and anesthetist) as well as special anesthesia equipment are eminently desirable for all major primary thoracic operations. If not available I believe that routine conservative treatment which was generally practiced and yielded a measure of satisfactory results in the first World War, is in order. Makeshift operations or operations by those without experience should have no place in this field. Given a trained operating team thoracic wounds in general offer an unusually favorable field for early and complete recovery much more favorable than cranial or abdominal wounds for example. The objective should be the restoration of cardiac function and full expansion of the lung. There is thus avoided the intra-thoracic crippling which is prone to occur from organization of retained blood clot and exudate. Indications for a primary operation by a trained team are (1) continuing hemorrhage (2) the definitive closure of an open pneumothorax (3) laceration of the lung (4) removal of foreign bodies and (5) a wound of lung and/or of chest wall requiring debridement.

Positive pressure anesthesia is imperative for primary intrathoracic operations in my opinion because expansion of the lung is to be achieved from the outset if possible. Cyclopropane is a particularly desirable anesthetic in this field. Intratracheal anesthesia has been recommended but appears to me to be unnecessary even for the most extensive operations. Positive pressure anesthesia with the customary mask makes



### *Outline of Treatment for Severe War Wounds of the Chest*

possible the safe opening of the thoracic cavity to any desired extent. The removal of foreign bodies and debridement of the lung are facilitated by at least partially controlled respiration (carried out by the simple expedient of rhythmic pressure on the bag). Extensive pulmonary lacerations may require partial or complete lobectomy or even pneumonectomy. Scarcely any primary thoracic operation would be terminated today without pleural pouddrage with one of the sulfonamides. Most thoracic wounds should be completely closed; when accumulations of air or blood are to be anticipated, closed under-water drainage toward the bottom of the chest is a safety measure. Special requirements after operation may be (1) the administration of oxygen by means of a mask, (2) bronchoscopic suction which may be life-saving in cases of accumulated secretion in bronchi and bronchioles, and (3) the control of abdominal distention chiefly by the passage of a Levin tube.

Turning to the question of the treatment of major thoracic wounds which do not require primary operations, many perforating rifle bullet wounds, for example, the chief problem is the management of hemothorax. The simple withdrawal of fluid is advocated by some, with the addition of air replacement by others. In either case it should be noted that prolonged retention of blood may lead to crippling peripulmonary fibrosis, to pleural infection, or to both.

While primary operations deal with recently inflicted wounds, secondary operations are concerned essentially with infections in the pleural space. Single encapsulations of pus are unusual. Therefore, careful preoperative study of x-ray films are necessary in order to locate the foci of infection which will be encountered. A liberal operative exposure will usually be required. The problem of traumatic pulmonary abscess, whether due to infection, to foreign body, or to both, requires special consideration particularly from the viewpoint of precise localization in order to achieve accurate surgical approach. Some aspects of non-penetrating wounds of the chest, a subject which has not been touched on, can be referred to only in passing. An atelectatic pneumonia may result from a contusion of the chest wall. Fractured ribs may tear the lung with resultant tension pneumothorax or mediastinal emphysema. Crushing chest injuries often are characterized by the lividity of traumatic asphyxia and at times by extreme dilatation of the stomach. A special feature of the present war is the remarkable and horrible "blast injury" of the chest producing extensive hemorrhages into the lungs. These pulmonary lesions apparently are due to concussion or commotion, for there may be no external injury. The stricken individual is in shock, with dyspnea and cyanosis, suffers thoracic and abdominal pain,



and presents abdominal rigidity not accounted for by other injuries

In the allotted space only injuries limited to the chest have been considered. In closing, reference should be made to concomitant wounds which may require precedence in treatment, and finally, to thoracic-abdominal or abdominothoracic wounds, often of grave significance, in which the abdominal component may and often does require more urgent attention



## SOME ASPECTS OF CLOSED WOUNDS OF THE CHEST

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### Suggested Program of Treatment

Prophylactic chemotherapy should be given as early as possible in every case, on lines similar to those recommended for other war wounds (Fuller and James, 1940). The possibility of prophylactic local application of sulphonamide drugs to the pleura by injection of suspensions of the drugs in a suitable vehicle seems as yet to be unexplored; local application to wounds elsewhere has been successfully used. Though local application to the pleura in cases of established infection with empyema has been disappointing, the method seems well worthy of trial as a prophylactic against the development of infection.

Immediate surgical treatment is necessary for cases showing the indications already described under "Surgical Intervention." Wherever possible, this and other forms of treatment should be planned after study of radiographic appearances.

In cases with "closed" wounds not showing indications for immediate surgical intervention, and those in which after necessary surgical treatment the chest has been closed (according to the indications outlined above), treatment should be planned to keep the pleura free from blood and exudate by aspiration, and to manage the pneumothorax most advantageously. These questions receive further consideration below.

Surgical intervention on the usual lines is required later for such conditions as empyema, pulmonary abscess, etc.

### Management of the Closed Thorax after Penetrating Wounds

In most cases there will be varying amounts of blood and air in the pleura. The advantages of keeping the pleura free from blood and exudate seem overwhelming; the risk of infection, especially by anaerobic organisms, developing in spite of prophylactic chemotherapy is probably much less, and the occurrence of disabling pleural thickening and pulmonary fibrosis by partial organization of the slowly absorbing blood and exudate is avoided. The drawbacks are that unless efficiently performed early aspiration may be exhausting to a shocked patient; that aspiration may be difficult on account of fibrin clot which blocks the needle; and that simple aspiration may result in the recurrence or increase of bleeding by causing re-expansion of the partially collapsed lung. The latter danger may be avoided by air replacement at all early aspirations; this should certainly be done if there is evidence of pulmonary haemor-



rhage in the form of bright haemoptysis. With these points in mind the following list of indications may be suggested.

(i) *Aspiration and Air Replacement*—These are indicated in all cases in which within a few days of wounding there is a considerable haemothorax. The indication for air replacement is not so strong if no haemoptysis occurs but if there is haemoptysis early aspiration should be accompanied by air replacement. Air replacement is contraindicated if there is evidence of a pleural infection.

(ii) *Simple Aspiration*—This is required in cases seen later in which there are signs of considerable effusion into the pleura but without haemoptysis and in cases in which a pneumothorax has been present for several days, haemoptysis has ceased and there is a reaccumulation of fluid especially if the temperature and pulse are rising suggesting incipient infection. In the latter type of case the object of treatment should be to secure re-expansion of the lung to minimize the size of the empyema that may develop.

(iii) *Artificial Pneumothorax*—The cases considered under heading No. 1 will be left with an artificial pneumothorax. In a few instances a wound of the lung may be causing haemoptysis without any considerable haemothorax or traumatic pneumothorax. In these if haemoptysis continues the formal induction of an artificial pneumothorax may be a very satisfactory line of treatment. In any case when an artificial pneumothorax is induced by either of these methods it should be maintained for a few days only possibly no refill or at most only one will be required. As soon as active pulmonary haemorrhage has ceased as shown by the disappearance of the bright blood from the sputum no further refills should be given and the lung must be allowed to re-expand slowly by spontaneous absorption of the air in the pleura. The value of artificial pneumothorax has been emphasized on a basis of practical experience by Kretzschmar (1940).

### Technique of Aspiration

A few words about the technique of aspiration of the chest may be useful. Three points require attention: first the patient must be supported comfortably in a convenient position both so that he is not exhausted by the effort of maintaining it and so that the operator is not incommoded by difficulty of access to the chosen site; secondly the common error of inserting the needle too low must be avoided and thirdly a needle of adequate bore for the type of fluid present must be used.

*Posture*—There may be factors such as the site of external wounds which influence decision about the most suitable posture. In most cases



### *Some Aspects of Closed Wounds of the Chest*

however, that shown in Fig. 1 is possible and is very convenient. The patient sits propped up in a rather upright Fowler's position; with the arm of the sound side he clasps a blanket or blankets rolled into a cylinder about sixteen inches to eighteen inches long, while the arm of the affected side is placed so that the hand rests on the opposite shoulder and the elbow rests on the top of the rolled-up blanket. This posture leaves the whole of the latter wall of the chest accessible to the operator sitting by the bedside. It can be maintained without distress even by an ill patient.



FIG. 1.—A useful position for aspiration of the chest, air replacement, etc.

*Insertion of Needle.*—In most cases of effusions into a free pleura the needle should be inserted in the fifth or sixth intercostal space in the mid-axillary line with the patient in the position described. The disadvantage of inserting the needle lower than this is that it is apt to get intermittently blocked by the diaphragm at the height of its excursion, that fibrinous particles are more numerous in the costo-phrenic "gutter," and that this "gutter" is in any case more narrow in its lower part, so that it may easily be almost obliterated by fibrinous deposit on the pleura. These troubles are minimized by inserting the needle higher up; if this has been done the last part of the fluid may be withdrawn by leaning the patient over towards the affected side.

*Size of Needle.*—The importance of using a needle of adequate bore seems too obvious to require emphasis. There is one difficulty, however—namely, that most large-bore needles are made much longer than necessary for pleural aspiration. Those supplied with most of Potain's aspirator sets are an example of this. Very few chest walls require a needle more than two inches in length; and unnecessary length partly



defeats the purpose of a wide bore needle by increasing the resistance to flow. Aspiration of a haemothorax may prove very difficult on account of repeated blockage of a needle of the usual sort, even of wide bore. In such cases it is tentatively suggested that larger trocars and cannulae, such as are used for the insertion of intercostal catheters or for thoracoscopy, might be tried. A trocar and cannula of this size can be inserted painlessly if the technique is sufficient careful. The chosen site must be adequately anaesthetized, 20 c cm of local anaesthetic solution being required. The presence of fluid is confirmed, a small incision is then made with a fine scalpel or tenotomy knife, and through this the trocar and cannula are steadily thrust between the ribs into the pleural space. Aspiration through such a large cannula, if thoroughly performed, would rarely need to be repeated. It might be advisable to irrigate the pleura with normal saline at the end of such an aspiration to ensure that no fibrinous debris is left to interfere with subsequent aspiration through a more normal needle, should it prove necessary. During this procedure the interpleural pressure should be controlled by introducing or removing air through a second needle inserted higher up, as described below under air replacement. After withdrawal of the trocar the small wound should be closed by a single stitch, and a dressing, firmly supported by elastic plaster applied.

### Technique of Air Replacement

Air replacement requires, in addition to aspirating apparatus, devices for measuring the intrapleural pressure and for admitting air, preferably in measured volume, into the pleura. These are, of course, both provided by any form of apparatus used for artificial pneumothorax work. Preparations having been made for aspiration as outlined above, a second needle is introduced, in the manner described for measuring the intrapleural pressure, higher up above the level of the fluid. Through this, as the fluid is withdrawn through the lower needle, air is admitted at such a rate that the intrapleural pressure is kept as constantly as possible at the desired level. The pressure required in the individual case can be judged from the degree of lung collapse initially present and the initial pressure before aspiration is begun. In general, in order to maintain constant pressure within the pleura rather less volume of air must be introduced than fluid withdrawn. The pressure required to produce a useful degree of lung collapse varies greatly. It will always be below atmospheric in men with previously healthy lungs—generally the mean pressure will lie between 0 and -4.

If a pneumothorax apparatus is not available the pressure may be



### *Some Aspects of Closed Wounds of the Chest*

measured by the employment of a manometer, and the aspiration stopped occasionally to allow air to be injected through the lower (aspirating) needle with a large syringe, the amount being controlled by observation of the intrapleural pressure. This is a safe procedure, provided it is certain from the free flow of fluid on aspiration that the needle is in the fluid-containing space.

If there is a large haemothorax with no considerable air space above it, and an air replacement is indicated, the easiest procedure is to start as for simple aspiration. When about 100 c.cm. of fluid has been withdrawn inject 80 c.cm. of air through the aspirating needle, and continue thus until a useful air space is present above the fluid. Insert the upper needle into this, and proceed as in the cases with an initial air space.

*Infection.*—This complication should be watched for throughout. So long as fluid accumulates in the pleura specimens must at intervals be examined bacteriologically, by both aerobic and anaerobic culture, especially if the temperature rises or fails to fall. It is to be hoped that the incidence of infection will be reduced to a very low level by prophylactic chemotherapy and thorough early aspiration. When it occurs the case must be treated on the general principles of the treatment of pleural infections, which cannot be discussed here. It may be stressed that so long as there is a pyothorax—i.e., a collection of purulent fluid in a free pleura—aspiration or drainage by an efficiently closed method must be used; only when the condition has settled into a localized walled-off empyema may an open method of drainage be employed.

#### **Tension Pneumothorax**

This is a rare complication of chest wounds; it results from a pleuro-bronchial communication of valvular type, so that air can enter the pleura *in inspiration and cannot leave it during expiration*. The pleura thus becomes distended by air under pressure, causing gross mediastinal displacement and dangerous respiratory distress.

The presence of a tension pneumothorax may be suspected when there is extreme respiratory embarrassment with cyanosis, and on examination the affected side of the chest is immobile, possibly distended, hyperresonant on percussion and either silent or (rarely) with curious amphoric respiratory sounds on auscultation, and the heart and possibly the trachea are displaced on the opposite side. The diagnosis is made precise by measurement of the intrapleural pressure, which will be above atmospheric.

Such a case calls for immediate measures for its relief. In emergency, with no apparatus to hand, relief may be obtained by simply thrust-



ing a needle into the pleura through one of the upper intercostal spaces. The outward hiss of air is easily audible if a tension pneumothorax is present, and confirms the diagnosis. This simple insertion of a needle brings the intrapleural pressure to atmospheric, and results in considerable relief of urgent symptoms. If the apparatus is available more information about the size of the valvular opening may be obtained by measuring the pressure, withdrawing a measured volume of the pleural gas to reduce the pressure a little below atmospheric, and watching for a time to see whether the pressure rises again. If it does not the needle may be withdrawn and the patient watched for recurrence of distress. If the pressure mounts rapidly or, after the needle has been withdrawn, distress recurs rapidly, a suitable needle may be inserted and connected to a rubber tube attached to a simple under water drainage bottle as used for closed drainage of empyemata (Fig 2). This will afford great

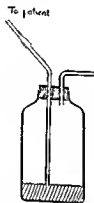


FIG 2—Simple under-water drainage bottle

relief, but has the disadvantage that, as air is expelled during cough, it may result in the development of a low intrapleural pressure, with too rapid re expansion of the lung, giving the pleuro bronchial fistula no chance to heal. It may be more satisfactory, in a patient who is not distressed by an intrapleural pressure equal to atmospheric, to leave a needle *in situ* open to the air, preferably through a loose cotton wool filter. If, however, the patient is distressed with an atmospheric intrapleural pressure the arrangement shown in Fig 3 may be used. In this, bottle B is added to the simple under water drainage bottle A to act as a safety valve, letting air into the system wherever the pressure gets below a level equal to that number of centimetres of water below atmospheric by which the tube C projects below the surface of the water in bottle B. This is of course adjustable to whatever level is required for



### *Some Aspects of Closed Wounds of the Chest*

relief of the patient's discomfort. The rather more complicated apparatus described by Marriott and Foster-Carter (1940) may be used for the same purpose.

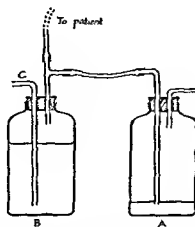


FIG. 3.—Apparatus for under-water drainage of tension pneumothorax, with safety-valve.

In general, in the treatment of valvular pneumothorax as little air as possible should be withdrawn or the pressure maintained as near atmospheric as it can be, in order to keep the lung as firmly collapsed as is consistent with the patient's comfort, since only thus has the pleuro-bronchial opening the best chance of healing. In valvular pneumothorax due to wounds surgical intervention will often be indicated; but the measures outlined above may be necessary life-saving preliminary steps.

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# GUNSHOT WOUNDS OF THE ABDOMEN

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Patients suffering from gunshot wounds of the abdomen, which are not immediately fatal may be saved by prompt treatment

In any such wound we have several serious factors to deal with, which must be handled promptly in order to save the patient

The location and extent of the injuries affect the outcome It is necessary to make a rapid diagnosis with an estimation of the damage that has been done also whether there is one or more wounds made by a bullet The nature of the injury and the estimate of the damage can roughly be made by estimating the number of bullets and noting their location Where there has been an injury by a shotgun the estimation of the damage is difficult because the shot may go in different directions They perforate intestines and blood vessels and do other damage in and about the abdominal region

The principal effects of a gunshot wound of the abdomen are (1) Hemorrhage (2) Shock (3) Perforation of the gastro intestinal tract with infection of the abdomen (4) Injury to the nerves or spinal cord (5) Injury to the diaphragm and lungs (6) Liver (7) Kidneys ureters or bladder

In most gunshot wounds of the abdomen it is necessary that the abdomen be opened and the damage repaired in so far as it is possible to do so It is absolutely essential that a well trained operating room force and every possible aid be immediately available for use during the operation

First an anesthetic should be used which will give complete relaxation of the abdominal muscles Without this little or nothing can be accomplished The patient must be as free as possible from nausea and vomiting We have found spinal anesthesia the most suitable for this purpose—notwithstanding the presence of severe shock and hemorrhage In many cases we have found that the spinal anesthesia does not produce additional disturbance but it aids greatly in relieving the patient's shock and distress

The second important point is an abdominal incision which will enable the entire abdomen to be carefully explored or at least the part in which any possible damage could have been done Perforation of the intestines and stomach should be repaired and the bleeding vessels ligated with a minimum loss of time



## *Gunshot Wounds of the Abdomen*

A third necessity is a suction apparatus with which blood may be aspirated from the abdominal cavity without increasing the trauma and shock. This is far superior to the use of sponges. A suction pump in which two suction tubes are available for use at the same time not only expedites the operation greatly but prevents trauma to the peritoneum.

In most gunshot wounds of the abdomen, an X-ray should be made and quickly developed, especially if the location of the bullet is in question. The X-ray may be developed while the patient is being taken to the operating room and prepared for operation.

It is important too that, during and immediately after operation, glucose and saline be available for intravenous administration. Donors should be available for blood transfusion while the patient is on the table, or immediately afterwards. There is often a great deal of shock and much loss of blood, which can be best combatted by blood transfusions. The blood given should be sufficient to replace the blood lost. It is of greatest aid in counteracting the shock.

After the abdomen is opened and the blood removed by aspiration, the bleeding vessels should be ligated. Packing is of great help in controlling bleeding from the liver. The intestines and stomach should be carefully explored and mesenteric perforations repaired. If there is only one bullet wound and this is out of the reach of the small intestines and only the stomach involved, the search for perforations is simplified. If there has been more than one bullet wound and the small intestines are involved, or if there has been a gunshot wound, there may be multiple perforations, and each of these must be located and closed.

Sometimes it is necessary, where the intestine is badly damaged, to resect a segment of the small intestines. In one case, it was necessary to resect two segments. It is important, however, to locate every perforation or injury to the intestines and see that these are properly repaired before the abdomen is closed. Proper relaxation, under spinal anesthesia, lessens the time necessary for repair and decreases shock.

In injuries to the spleen, it is often necessary to remove the spleen through the abdominal incision. A badly injured spleen, of course, should not be sutured. Almost any injury to the spleen may require a splenectomy and this should be done without hesitation. It usually offers the best chance for the patient's recovery.

Sometimes the diaphragm is injured. A single bullet may do considerable damage to the diaphragm. A shotgun wound may make a considerable opening which will require suturing. Before suturing the diaphragm, however, it is well to put the suction apparatus inside the pleural cavity and see if there is any blood present, find the source of the



blood and stop the flow immediately, in addition to closing the opening in the diaphragm

In liver injuries, the use of the coagulating current may be helpful in stopping the bleeding. The liver may be sutured by using special needles, or it may be best to pack, depending upon the nature of the injury. In all cases the bleeding must be controlled at once and this in such a way that packing, if used, may be removed later without difficulty.

After the abdominal injuries have been taken care of, the incision is closed, often without drainage. There may be times when drainage is advisable but in most cases it is not.

In perforation of the intestines and soiling of the abdomen, one would expect infection. In this case it is necessary that the wound be closed with figure of eight sutures of silkworm gut wherever possible to do so.

Post operatively the patient should receive blood transfusions, glucose and saline and every other possible aid that would help to relieve shock, prevent infection and help the patient over the next few days which is, of course, the trying time.

Perfringens antitoxin should be used and, in addition to this, X ray treatment. These seem to materially decrease the incidence of gas gangrene.

Every possible aid in the prevention of gas formation should be used. Pitressin should be given regularly unless there is some contraindication. If necessary, a small Levine tube should be left in the stomach and aspiration done at regular intervals. A rectal tube may be inserted when there is gas in the large intestines. It is of the greatest importance that abdominal distention be prevented as this usually results in an increase of the toxic absorption and aids in the extension of infection from the bowels. The first few days after the injury are the most important. It is during this time that the patient must receive every possible care and attention. Naturally, the longer the waiting period from the time of injury until surgical treatment is available has an adverse bearing upon the patient's recovery.

Infected wounds respond to the local applications of Azochloramid in Triacetin or in olive oil.

In the twenty year period from January 1, 1920 to January 1, 1940 more than 150 gunshot wounds of the abdomen have been operated upon in this clinic. Our results have been uniformly good. Some cases were apparently hopeless from the start but we have noted that a number of those cases in which we thought at first the patient had no chance at



## *Gunshot Wounds of the Abdomen*

all made a good recovery. This leads us to the conclusion that all cases should be given every opportunity to recover, and recovery usually depends upon immediate surgical treatment.

Four case reports of recent injuries follow which illustrate certain points.

We have used spinal anesthesia routinely in practically all of these cases and find it the most satisfactory anesthesia, especially where perfect relaxation is required for quick exploration and rapid surgery.

### **Illustrative Case Reports**

*Case I.* J. T., male, age 16, white, admitted November 25, 1938 with an abdominal gunshot wound, which he received when the gun fell to the ground. The wound was about four inches in diameter, situated in the right lower quadrant with evisceration of part of the small intestines. An immediate operation was performed under spinal anesthesia.

- Operation:*
1. Extension of gunshot wound to right upper quadrant.
  2. Evacuation of blood, shot and wadding from abdomen.
  3. Closure of large wound in stomach.
  4. Suture of large wound in liver after debridement.
  5. Removal of greater portion of gall bladder with cholecystostomy (tube brought out through stab wound to right of incision).
  6. Debridement of anterior abdominal wound, removing greater portion of the right rectus muscle.
  7. Peritoneum closed with cromatic catgut #2.
  8. Muscle, fascia and skin closed with through-and-through silk-worm-gut sutures.

*Findings:* There was a large wound about four inches in diameter through the lower portion of the right rectus muscle, through which the transverse colon and about ten feet of the small intestine protruded. The wound edges were very ragged. There was a large swelling above this, where the shot had traveled upward and slightly inward, tearing away most of the right rectus muscle and leaving contused muscle, shot and wadding. There was a hole in the pyloric end of the stomach extending from the pylorus upward for about five inches along the anterior surface, through which the stomach contents were escaping. The gall bladder wall was thickened due to subserosal hemorrhage. There were several small perforations in the upper portion. The greater portion of the shot and wadding had passed just to the right of the gall bladder, practically tearing it free from its bed. This had split the lower edge of the liver upward for a distance of about four inches. The greater



portion of the wadding was found embedded in this part of the liver which was contused. There was a moderate hemorrhage into the mesentery of the transverse colon but no bleeding points could be located. The serosa was undermined with hemorrhage up to the anterior transverse band of the colon, which appeared to be viable. For this reason, it was thought advisable not to disturb this further. The liver bed was carefully debrided and through and through sutures taken to control hemorrhage. The stomach wound was closed in a transverse manner and part of the hemorrhagic omentum sutured over this. The entire abdomen was filled with blood and debris, along with gastric contents and bile. The patient was in shock and was given one transfusion during operation and another soon afterwards. It was necessary to remove the greater portion of the rectus muscle along with a large amount of subcutaneous tissue, which was blackened and contained many small shot. The patient is to be given other transfusions. X ray treatment to the wound and tetanus and perfringens antitoxin.

*Prognosis* It is very unlikely that the patient will survive due to the severity of the abdominal trauma.

Three blood transfusions were given after operation. Death ensued within twenty four hours.

*Case II* T. B. aged 28 male, white, was admitted to the hospital June 10 1939 with a gunshot wound in the left upper abdomen of two hours duration. Patient was operated immediately under spinal anesthesia.

*Operation* The point of entrance was above and slightly to the left of the umbilicus. The bullet perforated both the anterior and posterior walls of the stomach and severed some of the blood vessels and the transverse mesocolon. The bullet ranged backward and injured the tail of the pancreas and the left kidney. The lower pole of the left kidney was lacerated and bleeding freely. A careful examination of the entire abdomen did not reveal any other trouble. The openings in the anterior and posterior stomach were carefully sutured. The stomach was carefully aspirated before the anterior opening was closed. The mesocolon was carefully explored and the bleeding vessels tied off. The exploration backward revealed the injured kidney and this was so serious that it was necessary to do a left nephrectomy, which was done transperitoneally. A drain was inserted in the cavity just back of the stomach and also one in the left renal fossa, and both brought out through a stab wound. The incision was then closed.

*Findings* Gunshot wound of the wall of the abdomen with perforation of the anterior and posterior walls of the stomach with severe injury to the lower pole of the left kidney and also to the renal vessels.



## *Gunshot Wounds of the Abdomen*

This necessitated removal of the left kidney after suture of the perforations in the stomach and tying off the blood vessels in the transverse mesocolon.

One blood transfusion was given post-operatively. Convalescence was complicated by wound infection which drained for six weeks.

*Result:* Patient discharged from the hospital July 1, 1939. He is working regularly at the same position before injury. No disability.

*Case III.* J. F., colored, age 23, admitted to the hospital September 27, 1939 with a gunshot wound. Wound of entry middle of right lower rectus muscle. The abdomen was rigid. Patient was unable to raise the right foot. X-ray showed the bullet to be resting in the bone of the acetabulum. Patient was operated upon immediately under spinal anesthesia.

*Operation:* 1. Low right rectus incision with excision of wound.

2. Ligation of right inferior epigastric artery.

3. Ligation of right internal iliac vein with evacuation of large amount of blood from retroperitoneal space. (About one quart evacuated from the abdominal cavity.)

4. Closure of five perforations in the upper ileum.

5. Closure of two perforations in mesentery to upper ileum.

6. Closure of two perforations in transverse colon.

7. Two rubber tissue tubular drains placed in retroperitoneal space.

8. Four rubber tissue tubular drains placed over brim of right pelvis and brought out through lower end of incision.

9. Incision closed.

*Findings:* There was a small puncture wound of entry in the lower and middle portions of the right rectus muscle. This ruptured the right inferior gastric artery and passed through the peritoneum perforating the middle portion of the transverse colon in two areas. There were five perforations in the upper end of the ileum with two perforations of the mesentery to the ileum. There was some escape of intestinal contents around the perforations. There was about one quart of blood in the peritoneal cavity. The bullet ranged downward and backwards, severing the posterior peritoneum over the internal iliac vein. There was about one quart of blood in the retroperitoneal space. This was evacuated and the vein ligated. Due to the large amount of oozing present, two rubber tissue tubular drains were placed in this region. Four rubber tissue tubular drains were placed over the brim of the pelvis, in the region of the perforations. The tract of the bullet was followed downward with the exploring finger and was found to have coxal bone just on the inside of the acetabulum.



Patient was given four blood transfusions in the first five days of convalescence. Temperature ranged between 102 and 104. Moderate sloughing of the lower end of the wound followed by rapid healing in three weeks.

*Result* Patient completely recovered.

*Case IV* M B age 17 white male admitted to hospital October 12 1939. Patient was accidentally shot in left upper chest. Moderate shock and anemia. Patient operated immediately under spinal anesthesia.

*Operation* 1 Abdominal section. High left rectus incision.

2 Exploration of entire abdomen.

3 Splenectomy.

4 Five perforations in stomach closed.

5 Bleeding vessels in omentum closed.

6 Large perforation in diaphragm closed with catgut sutures.

7 Bleeding vessels carefully searched for and all that were bleeding were tied off.

8 Intestines carefully explored.

9 Colon carefully explored.

10 Stomach carefully explored.

11 Two soft rubber tissue tubular drains in splenic fossa and brought out through stab wound to left of incision.

12 Incision closed.

13 Debridement of wound in left loin region.

14 Four soft rubber tissue tubular drains two brought out above and two below in the wound which was very long and destructive in type.

15 Wound closed after debridement.

*Findings* The shot entered the left abdomen and ranged upward and somewhat inward. There were five perforations in the stomach but these did not perforate the posterior wall. There were some perforations of the vessels of the great omentum. These were tied off. The spleen was badly injured and the abdomen contained about one and one half pints of free blood most of which probably came from the spleen. It was therefore necessary to remove the spleen because of the extensive injury. The diaphragm was carefully sutured. No intestinal perforations were found.

The post operative course was stormy. Patient received six blood transfusions post operatively. There was a slight infection of all wounds. There was a collection of fluid in the left pleural cavity which was aspirated on one occasion.



### *Gunshot Wounds of the Abdomen*

*Result:* Good. Patient was discharged three weeks after injury. The wound was still draining a slight amount but this soon ceased and he is now well.

*Discussion:* There was subsequent infection in all of the above cases. They received combined tetanus and perfringens antitoxin and treated several times with X-ray therapy to the wounds. The first case was hopeless from the beginning, but it serves to emphasize the point that the external wound is no criteria of the extensiveness of the intra-abdominal damage. We must immediately explore and repair any damage found if we are to save many of these cases.



## SURGERY OF ABDOMINAL INJURIES

By CHAS GORDON HEYD, M D

*Professor of Surgery, New York Post Graduate Medical School,  
Columbia University, New York, N Y*

The imperative necessity for an army is to conserve and maintain an effective fighting force. The treatment of war casualties will be based largely upon this realistic conception. Wounded soldiers will have received (a) injuries of such a nature that the army may reasonably expect his return to duty, and (b) injuries of such a nature that the soldier cannot be expected to return to duty. War trauma to the skull and contents to the chest, grave compound fractures and injuries to the abdomen will be treated without any expectation of the return of the soldier to a combat unit.

The last forty years has witnessed a remarkable change in regard to surgical intervention for war wounds of the abdomen. In the Boer War, the Spanish American War, and for the first half of World War I, the noninterventionist attitude for abdominal war wounds prevailed. However, with the ability to move modern operating room equipment into the battle zone the interventionists gradually displaced the non interventionists.

The remarkable advance in modern warfare has introduced types of injuries that were only occasionally met with in World War I. The weight of projectiles and tempo of bombing, added to the dive bombing machine gun attacks have broadened the type and severity of injury. Present day bombs create innumerable secondary projectiles from fragmentation of anything that is in the path of the explosion. Two types of projectiles are thus created: the metal part of the shell, which is jagged, rough and of various sizes, and the secondary projectiles of rubble, metal, glass, and in fact anything and everything that may be activated and put in transit by the explosion of the bomb. Both carry into the body tissues additional foreign material in the form of clothing and underwear.

In no field of war casualties is the problem of surgical organization so important as in multiple compound fractures, injuries to the skull and contents, thoracic wounds and abdominal wounds. Therefore, surgical organization will imply mobile units that will bring modern operating room technic and equipment into the combat area. These types of war wounds are considered "nontransportable cases" and hence the effectiveness of small, self contained surgical units, with great mobility, capable of competent surgery within the battle zone.



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## *Surgery of Abdominal Injuries*

War casualties of the abdominal viscera are always multiple and severe, always associated with some degree of shock and hemorrhage and many patients will be exsanguinated; all will be complicated by a peritonitis of varying degree and 90 per cent will be associated with perforation of one or more of the viscera. The patients must be transported from the casualty area to the surgical unit. It is obvious that the soldier with minor injuries of the trunk and upper extremities will be able to walk from the battle area to the advanced medical post, while those that are injured in the abdomen will lie upon the battlefield until stretcher bearers arrive to transport them. Except for casualties the result of bombing and aeroplane machine gunning, the field of battle will obviously have to be cleared by an advance of the combat units before the abdominal cases can be picked up and carried back to the most advanced dressing station.

The surgery for war inflicted abdominal injuries is the application of technical procedures that are in no way different, except in degree, from the principles utilized in civilian traumatic surgery. The fundamental "technics" that are used in civilian surgery on the stomach, intestine and colon are the same surgical procedures that must be applied to the treatment of abdominal injuries sustained in war. These patients will all require adequate preoperative treatment, long anesthesia, relatively prolonged operations, extensive technical procedures, anti-peritonitis measures, plus sulfa drugs locally and by mouth; transfusion of whole blood and plasma and parental fluids. Furthermore, they will require prolonged hospitalization and postoperative treatment.

The time interval between the receipt of injury and operation and the adequacy of preoperative treatment will determine the mortality. The optimum time for an advanced surgical unit to receive abdominal casualties would be up to four hours and not later than six. There is very little gross soiling of the abdominal cavity even in penetrating wounds of the intestines up to four hours, and there is a relatively slight degree of peritonitis. The patient with an abdominal injury will reach the casualty receiving station: (1) moribund and dying; the indications here are to relieve pain and thirst, (2) in shock, but capable of resuscitation and (3) in fairly good operable condition. A warm body is one of the most reliable objective signs of operability. Refrigeration on the battlefield or in the ambulance during the trip back to the casualty receiving station, combined with shock and physical collapse due to the gravity of the injury and loss of blood, is an almost fatal combination of circumstances. The patient may be suffering from an internal hemorrhage and the only hope of stopping the hemorrhage will



be by operative intervention, with simultaneous blood replacement

Mortality is inversely proportioned to the "time interval period," that is, the time between the receipt of the injury and the time of operation. Shock, hemorrhage and peritonitis are the outstanding causes of death

The relative trajectory of the projectile may be visualized in many cases by an examination of the wound of entrance and exit if and when both are present. Deflection of the projectile is to be expected in injuries received in the area of the buttocks or from the thigh upward. The projectile will be deflected and its course deviated by hitting bone or penetrating the bony pelvis. The position of the patient, standing, squatting or lying, the status of the bladder in regard to its fluid content, will also determine the extraperitoneal or intraperitoneal injury of the bladder and rectum. Every patient upon whom a laparotomy is contemplated should be catheterized just before operation as it subserves two purposes. To indicate roughly an injury of the urinogenital system or the absence of urine in the bladder, and finally to have a collapsed bladder during the laparotomy.

The operative indications are more simple than the procedures that will be employed. Every abdominal case in fair operable condition requires surgical intervention. No wound of the external abdominal parietes should be considered insignificant. A projectile may go through five or more loops of bowel and pass through or lodge in the solid viscera. A projectile may not enter the peritoneal cavity but nevertheless produce widespread intra abdominal injury by the force of impact. Every operation for an intra abdominal war injury should be undertaken as a complete abdominal exploration.

War injuries of the abdomen may involve one or more of the abdominal viscera. They are usually associated with injuries of the thorax, retroperitoneal tissues including kidney, and with the extra peritoneal portions of the rectum and bladder. Ten per cent of the injuries of the thorax will be complicated by injury to the upper abdominal viscera. Combined thoraco abdominal injuries passing from side to side or from the right or the left side, are relatively benign. The projectile may pass through both sides of the costophrenic sinus traverse the liver on the right side, or the spleen on the left, producing a variable amount of damage to these organs but not perforating the intestine or stomach. Wounds of the stomach will be complicated by injury to other viscera in at least one third of the cases. Twelve per cent of abdominal injuries will have an associated injury to the diaphragm and chest, 10 per cent will be associated with an injury to the



## *Surgery of Abdominal Injuries*

kidney; 10 per cent of injuries to the liver will be associated with injury of other abdominal viscera. The bladder will show a concomitant injury in 5 per cent of the cases and the spleen in approximately 6 per cent. War injury of the large bowel will carry with it a higher mortality and 40 per cent will be associated with injury to other abdominal viscera. The incidence of injury to the retroperitoneal tissues is high whenever the colon is injured. Infection of the retroperitoneal tissues is severe and rapidly fatal due chiefly to the virulence of the anaerobic flora that arises from the colon. The exploration of the colon must be particularly thorough.

The presence of a considerable quantity of free blood in the peritoneal cavity suggests that a main vessel has been injured. Every injured viscus will bleed, the liver and spleen, in great degree, and the finding of a large amount of blood makes it imperative to locate the source of the bleeding at the very beginning of the laparotomy. The abdominal viscera should be explored systematically: (1) the small intestine, (2) the colon, (3) spleen, liver and stomach, and (4) bladder and rectum. All of the small intestine should be inspected from the angle of Treitz to the cecum before any attempt is made to repair the perforations. As each perforation is encountered it should be occluded temporarily by rubber compression clamps for it may happen that five, six, seven or more perforations are all within two or three feet of bowel and one resection will be better than the consecutive closure of a variable number of perforations.

The detachment of the mesentery at its attachment to the small intestine of more than 5 cm. will almost inevitably result in death of that portion of the bowel. Aseptic resection with blinding of the ends and then a lateral anastomosis will be the safest procedure as it is estimated that a lateral anastomosis provides about 10 per cent greater safety than end-to-end anastomosis. In general, the closure of intestinal perforations by enterorrhaphy is attended with less mortality than resection. The danger of a subsequent postoperative intestinal obstruction is not great as a small bowel lumen will suffice for the passage of the fluid contents of the small intestine. If any doubt arises at the time of operation in regard to patency after enterorrhaphy, a lateral anastomosis may be easily and safely performed.

In wounds involving the lateral and anterior abdominal wall the best practice is to complete the laparotomy first and then give attention to the entrance and exit wounds. These wounds should be completely resected by mass excision of the tract with a surrounding area of healthy tissue from the surface of the abdomen through the muscular parietes



into the peritoneal cavity. The most practical incision is a midline incision. This incision may be extended either up or down, or laterally, and provides an excellent exposure except for the extraperitoneal portion of the rectum which should be explored by a parasacral incision.

Every injury received in or about the region of the buttocks must be suspected of having injured the extraperitoneal and sacral portion of the rectum. All wounds involving the posterior portion of the trunk and buttocks should receive surgical attention before the laparotomy and not afterward. The turning over of a recently laparotomized patient to take care of posterior wounds is attended with a sudden pronounced return of shock.

Shock and resuscitation will be reduced by timely and adequate preoperative treatment. Sedation, water balance, whole blood and plasma transfusions will return many patients to a fairly operable condition. Peritonitis, retroperitoneal infection and gas infection will be combatted by the administration of the sulfa drugs by mouth or intramuscularly and by local application. Death from hemorrhage may be prevented by prompt transportation, adequate preoperative treatment and timely surgery.

The effectiveness of abdominal surgery for war casualties and the final outcome of the salvage of lives will depend largely upon the organization of the advanced surgical units that must take care of the grave nontransportable casualties. Low mortality will depend upon (1) available transportation and accessibility for transfer in and out of the combat area, (2) well trained ancillary groups for the treatment of shock and hemorrhage. These terms will be concerned with preoperative preparation—the treatment of shock—the giving of whole blood or plasma transfusions and parenteral fluids, (3) a highly trained experienced operating unit of individuals that have worked together over considerable periods and (4) sufficient facilities for the longer hospitalization after operation than obtains in the other fields of war surgery.

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## ABDOMINO-THORACIC INJURIES

By GORDON GORDON-TAYLOR, O.B.E., M.A., M.S., F.R.C.S., F.R.A.C.S.  
*Temporary Surgeon Rear-Admiral*

Popular opinion is accustomed to associate penetrating injuries of the trunk with grievous mortality, and statistical inquiry only too truly confirms the fatality of wounds implicating the thoracic or abdominal cavity under conditions of modern warfare. The ancients knew the lethal character of wounds of this portion of the human frame; it suffices to mention here the wound of Eurymachus from the arrow from Odysseus's powerful bow, and the injuries inflicted upon Polydorus and Tros by the great Achilles or on Sarpedon by the spear of Patroklos—all these abdomino-thoracic wounds recounted in the Homeric epics proved fatal. The English stage and Scottish history also testify to the gravity of the abdomino-thoracic injury: in Shakespeare's drama, Macbeth unseamed Macdonald from "nave to chap" in the manner of one accustomed to wield the claymore. The backhand of the claymore could easily split a man from clavicle to thigh: many of General Mackay's soldiers perished in this way, endeavoring with their muskets to protect their heads and trunks in that fierce overwhelming rush of Graham of Claverhouse's men at Killiecrankie.

The surgery of those regions which adjoin the midriff is not entirely modern. The behavior of wounds of the diaphragm received in warfare has been known to surgeons since the days of Ambroise Pare, and was accurately noted and discussed by Guthrie when writing of the war surgery of the Napoleonic era. The surgical treatment of thoracic wounds by Guthrie and by Baron Larrey, Napoleon's Surgeon General, has improved no inaccurate presage of the modern treatment of gunshot injuries of the chest. In respect of the repair of visceral injuries on the abdominal aspect of the diaphragm, over six centuries have rolled past since Henri de Mondeville counselled suture of the colon and affirmed the recovery of some of those who had received wounds of the large intestine.

Injuries which involve thorax, diaphragm, and abdomen may be of penetrating or of non-penetrating character. In the war of 1914-18 the first-named group completely overshadowed and outnumbered those which were subparietal lesions.

### On Penetrating Abdomino-Thoracic Injuries

In one series of cases from the war of 1914-18 (Sir Cuthbert Wallace, 1922) abdomino-thoracic cases constituted 12% of the abdominal cases



which reached the casualty hospitals of an army the operations performed on this group of patients also accounted for 12% of all the abdominal operations in that army. In the Spanish Civil War the proportion of abdomino thoracic wounds in all wounds of the belly admitted to a hospital of first urgency was not dissimilar to that which obtained in 1914-18—i.e. 11% (Jolly 1940). Abdomino thoracic injuries formed 9% of a certain series of thoracic cases admitted to a clearing station (Gordon Taylor) during 1918.

Statistics of abdomino thoracic wounds culled from the Official History of the War of 1914-18 demonstrate that in a vast majority the abdominal lesion determines the gravity of the prognosis and further that wounding of the hollow abdominal viscera greatly augments the

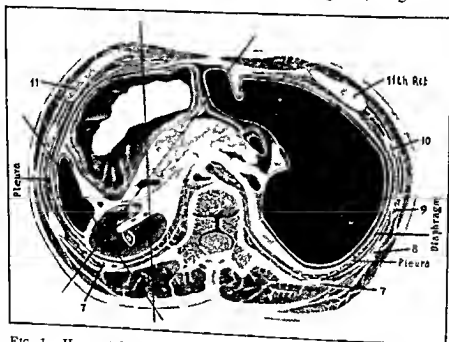


FIG 1—Horizontal sect on through abdomino thoracic zone to demonstrate the organs liable to injury in penetrating wounds of this area

fatality of the injury. The most fleeting glance at any anatomical atlas will demonstrate those organs most likely to suffer in abdomino thoracic injury (Figs 1 and 2). It will at once be apparent that the anxieties occasioned by a wound of the left dome of the diaphragm must greatly exceed those which are aroused by right sided penetration of the midriff. In this discussion I am utilizing the excellent classification of penetrating abdomino thoracic wounds given by my friend Tudor Edwards.

1 The chest and abdomen may be penetrated by separate missiles the wounded man sometimes becoming a veritable St Sebastian his abdo



## *Abdomino Thoracic Injuries*

men and chest riddled with fragments of high explosive or machine gun bullets

2 Missiles may penetrate the chest and may emerge through the abdominal wall or be retained within the belly on the other hand the track of the missile may be in the reverse direction—the wound of entry in the abdomen and the fragment retained within the thorax

3 Traversing wounds of the lower chest, especially if inflicted during expiration may pass through the diaphragm and occasion damage to the abdominal organs lying immediately subjacent to the midriff

4 Tangential wounds of the lower thorax in which considerable

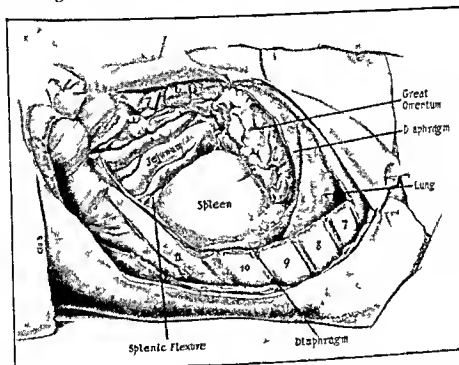


FIG 2—Dissection of the left sided abdomino thoracic region showing viscera liable to injury in penetrating wounds (Prepared by Prof John Kirk Middlesex Hospital)

damage, including diaphragmatic injury and perforation is produced by the missile and in driven fractured ribs ( stove in chest )

### **The Diaphragmatic Lesion**

The injuries of the diaphragm in abdomino thoracic lesions are mostly in the sloping muscular portion, and are specially frequent where this lies in contact with the thoracic wall In cases that come to operation the rent is usually small, in one series the linear tear was half an inch long or less in 50% of the cases Many openings are mere punctures larger



and the existence of other grave multiple injuries heavily load the scales against recovery

### Penetrating Injuries by Large Missiles

The injuries produced inside the abdomen by large fragments of metal or other foreign body are *almost always irrecoverable*, the result is scarcely likely to be different in those wounds if more than one cavity of the body is implicated. I have however, figured elsewhere a piece of brass tubing  $4\frac{3}{8}$  inches long removed from a Greek soldier, who recovered after the simple extraction of the missile which had passed from the middle of the right scapula and projected in the epigastrium (Gordon Taylor 1939)

Saint (quoted by Gordon Taylor) had a successful right sided abdomino thoracic case in which a fragment of shell weighing two ounces had traversed chest diaphragm and liver and produced two perforations of the duodenum and one in the hepatic flexure of the colon

In one of my patients the successful result of whose case is recorded elsewhere a missile weighing nearly four ounces produced the most grievous damage inside the belly and fractured the bony wall of the thorax (Gordon Taylor, 1919). The diaphragm was apparently uninjured and a strict observance of the approved nomenclature must therefore exclude this case from the category of the true abdomino thoracic

## TREATMENT OF PENETRATING ABDOMINO-THORACIC INJURIES

My contribution is only concerned with the surgical treatment of injuries of the diaphragm and of those abdominal organs whose anatomical proximity renders them specially vulnerable in cases of diaphragmatic wounding

### I Wounds Implicating the Liver

The dimensions and the velocity of the missile play an important part in determining the type of hepatic lesion which may be almost protean in character, large fragments of liver may be torn off and as much as one third of the right lobe has been found loose in the peritoneal cavity of a patient who recovered from a penetrating abdomino thoracic injury in the last war

Before their total destruction the examination of museum specimens in the College of Surgeons collection illustrating gunshot wounds of the liver revealed many lesions for which surgery must be futile or incom



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plete: thus it would be impossible by operative measures alone to prevent infection throughout the length of a ragged track running from the right lateral surface of the organ to its extreme pole on the other side of the body. In many cases of liver injury due to enemy action there are few arresting clinical signs, and it is significant that out of all the penetrating injuries of the abdomen which recovered in the last war without operation the wounds were mostly situated in the liver area. *Surgical intervention* directed towards the liver is indicated under the following circumstances only: (1) *gross haemorrhage from the liver*, which mainly depends on whether large veins in the organ have been injured—haemorrhage otherwise ceases spontaneously, as does oozing of bile, unless main ducts are severed; (2) the association of some thoracic or another abdominal lesion demanding exploration; (3) the retention of a missile in the liver, especially a large missile in an accessible position in that organ. In the case of severe laceration of the liver packing may be necessary to control haemorrhage. In some such patients the diaphragm may be sutured, and the thorax closed in the approved manner with airtight drainage of the pleura by means of a Malecot's tube inserted through a separate intercostal incision. The gauze pack is brought out through another separate incision in the anterior abdominal wall. In other cases the diaphragmatic opening may be enlarged parallel with its fibres from mediastinal to lateral border; the diaphragmatic edges are now approximated to the intercostal muscles and the pleura is thus shut off from the drainage track.

*Early jaundice* in cases of hepatic injury may be present, and is usually slight and evanescent; the possibility of a collection of bile in peritoneum or pelvis should always be considered. *Late jaundice* has a much graver significance, and indicates serious infection.

*Secondary hepatic haemorrhage* in penetrating abdomino-thoracic injuries is almost always fatal, and is usually associated with signs of sepsis such as pain, elevation of temperature and pulse rate, abdominal pallor, restlessness, and loss of strength.

The formation of an *intrahepatic abscess* round a retained fragment may be dealt with successfully by surgical measures.

## II. Gunshot Injury of the Spleen

A study of the specimens of *gunshot injury of the spleen* in the War Collection formerly housed in the Royal College of Surgeons used to suggest that wounds of that organ are frequently complicated by damage to adjacent viscera; yet in some collected clinical series it is stated that in more than half the cases of splenic injury revealed at operation there



was no damage to other abdominal organs. This was certainly not my experience (Gordon Taylor 1939) which is in agreement with that of Major Jolly in his surgical work with the Spanish Republican Army (Jolly 1940).

The propriety of primary splenectomy in cases of gunshot injury will still remain a subject of controversy. The removal of the organ should certainly not be resorted to lightly, but in my opinion the procedure has not greatly increased the risk. The suture of the spleen may not be difficult when the organ is approached through the chest and diaphragm but when explored by other routes cobbling of the organ is wasteful of time and may leave a sense of insecurity. Jolly (1940) and some of the Spanish surgeons write enthusiastically of splenectomy.

Numerous cases of successful transdiaphragmatic splenectomy in left sided abdomino thoracic wounds were recorded in the war of 1914-18 some of which were associated with the operative repair of injuries to the stomach (Richard Charles, Gask, J. E. H. Roberts, Lockwood, Bryan, Gordon Taylor, etc., and very recently by Valentine Logue). Recovery has even taken place in cases of left sided abdomino thoracic wounds in which left sided nephrectomy as well as splenectomy had to be performed for complete disruption of each organ (Gordon Taylor).

### III Wounds of the Pancreas

These injuries were less frequent in the war of 1914-18, or at any rate were less often recognized, than injuries of any other of the abdominal viscera. The intimate anatomical relation of the gland to the large blood vessels doubtless explains the paucity of wounds coming under the observation of the casualty hospital surgeons, doubtless some were unrecognized and were designated retroperitoneal haematomata. I have knowledge of only three abdomino thoracic injuries implicating the pancreas in which recovery took place (Saint Alan Curry, Gordon Bryan).

### IV. Injury to the Kidney

Each kidney is equally liable to damage. It was estimated that in 40% of gunshot wounds of the kidney investigated at an English surgical base in France during 1914-18 the thorax was also implicated. The propriety of immediate operation on the kidney in abdomino thoracic wounds demands even more careful consideration than in purely abdominal injuries. Probably the best course is to excise the wound leading down to the damaged kidney, the organ can then be inspected and any foreign body removed.

In the majority of cases the renal injury plays a minor part in menac



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ing life, and only for severe haemorrhage, a hopelessly pulped organ, or gross damage to the renal pedicle is primary nephrectomy indicated. In about 20% of cases of gunshot injury of the kidney in the last war life was threatened by secondary haemorrhage, consequent on sepsis, a retained missile, or an infarct of the kidney produced by damage to some branch of the renal artery.

### **V. Injury to the Hollow Organs**

Of hollow organs the *stomach and splenic flexure of the colon* are those most liable to injury; in suitable cases transdiaphragmatic laparotomy affords excellent access to these organs. Concomitant involvement of the *small intestine* denotes a more vertical track of the missile, and demands a separate approach or a much-extended incision. Each measure, though necessary, increases risk to life. Multivisceral damage also augments mortality, and vertical wounds, which may even extend from supraclavicular fossa to femur, tend to be very fatal.

The possibility of injury to the *duodenum* must be borne in mind, and any haematoma in its vicinity should be suspect, lest a retroperitoneal rupture of this fixed part of the small gut be overlooked. These cases were very fatal in the last war; successful cases have recently been operated upon by Rex Williams, Henry Thompson, and Hedley Atkins.

### **Summary of Treatment**

1. In many traversing (through-and-through) abdomino-thoracic wounds of the right side produced by a small-fragment no immediate active surgical treatment is required, provided that: (a) no gross damage has been inflicted upon the thoracic or abdominal wall—fractured ribs, explosive effect, etc.; (b) the direction of the track of the missile does not appear to compromise the general peritoneal cavity or suggest the desirability of its exploration; (c) the signs of abdominal haemorrhage or of injury to a hollow viscus are clearly absent.

2. In cases of right-sided abdomino-thoracic wounds in which a small fragment is retained in an inaccessible position in the substance of the liver an expectant line of treatment is the correct procedure; accessible fragments, unless of small dimensions, should be sought and removed.

3. When there is an open, blowing thoracic wound or a "stove-in chest," the chest wound should of course assume chronological priority of treatment.

4. If the position of wound of entry and exit in a left-sided abdomino-thoracic wound adumbrates a track implicating that fatal left sub-



phrenic area of the abdomen, or if a radiograph demonstrates a fragment of metal retained in this region, the thorax should be dealt with first and access to the upper abdomen obtained through the diaphragm.

5 When the thoracic injury appears insignificant but there is evidence of severe widespread intraperitoneal damage, especially involvement of hollow viscera, the abdomen should be explored through an appropriately placed laparotomy incision. This instruction applies to wounds of thorax and abdomen produced by the same or by separate missiles.

6 When the thoracic injury seems slight and when the evidence of a radiograph or the direction of a missile track in a through and through wound suggests an extra peritoneal course of a small fragment, such an abdomino thoracic injury may often be left alone.

If in such cases there is evidence of injury to the kidney the parietal wound down to the kidney should be excised, the organ investigated, and any foreign body removed.

7 In cases in which the thoracic wound is situated low down on the lateral or antero lateral aspect of the chest access to both supradiaphragmatic and infradiaphragmatic areas may be obtained by cutting through the costal arch after the manner of Bland Sutton, Duval, Berard, etc.

8 If an abdomino thoracic injury has been approached from the abdominal aspect, it is important not to waste time trying to complete a difficult suture of the diaphragm in a critically ill patient, unless the aperture in the midriff is so large that immediate or early herniation of the abdominal contents is certain to occur.

### Prognosis

In one large series from the war of 1914-18 it was found that operated abdominal cases (excluding abdomino thoracic injuries) gave a recovery rate of 51%, while abdomino thoracic wounds operated upon produced a recovery rate of 44.5%. But some series of abdomino thoracic cases in the casualty clearing zone gave a more favorable recovery rate than this. In the autumn of 1918 it attained the figure of 66.6% in the hands of certain surgeons in the British Fourth Army, and some operators (Jack Anderson Saint) who were perhaps fortunate in their percentage of right sided cases saved as many as 79 and 80% of their patients (Gordon Taylor, 1939).

Wounds that traverse the diaphragm from below upwards are said to be more grave than those in which the missile has passed from thorax to abdomen. In the former group an intestinal injury increases the seriousness of the prognosis.



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The mortality figures attending the surgical treatment of injury in one campaign are scarcely comparable with those of another war at a different period, in which the type of enemy missile, the degree of explosive force, the facility of transport from the field of battle, and other circumstances differ; but the steady improvement in the results of abdomino-thoracic cases from year to year in the war of 1914-18 was a memorable triumph of surgery.

### **NON-PENETRATING INJURIES OF THE ABDOMINO-THORACIC ZONE**

In contrast to the last great European conflict non-penetrating injuries of the abdomino-thoracic zone do not play the same small and infrequent part in war surgery to-day; the thoracic and abdominal viscera, solid and hollow, may be damaged under a variety of circumstances in "modern" warfare. Fragments or masses of timber, stone, or metal may be confusedly hurled with explosive force against chest and abdomen in the indiscriminate air bombardment of civilians; women and children have suffered "crush" contusions of thorax and belly from falling masonry and iron girders; visceral damage above and below the midriff may result from the blast of detonating bombs, mines, or other high-explosive machinery in close proximity to men and women of every age, condition, and calling, for in "total war" none can claim privilege or sanctuary. Nor does the diaphragm remain immune when chest and belly suffer violence.

#### ***Effects of Rupture of the Diaphragm***

Rupture of the diaphragm may be produced by the passage of a heavy vehicle obliquely across the abdomino-thoracic zone, by the crushing force of buffer accidents, or from the demolition and collapse of buildings. An excellent account of the injury has been given by Gordon Bryan (1922), who points out that the lesion is not very rare in children and adolescents, whose chest wall is more elastic and can be compressed to a considerable degree without fracture. In some cases costo-chondral dislocations may occur, as shown by some displacement of the chest wall and a clicking sound on respiration; at other times the diaphragm is torn by stretching or bursting, or may be lacerated by a fractured rib.

The convexity of the diaphragm is the part that usually suffers; on the rarest occasion the crus is damaged. The left side of the midriff is that most prone to rupture under such conditions of violence; the liver is more likely to bear the brunt of an injury due to compression of the



injury. An appeal may also be made to urographic methods of diagnosis.

It should be remembered that early exploration in a doubtful case will render this service to surgeon and patient—that a deliberate conservative resection of the damaged portion of the kidney can be considered at a period when urgency is not so extreme that only a hurried total nephrectomy can save life. In arriving at a decision, as to the exact technique to be employed in a case, it behoves the surgeon to remember the slogan: "First save the patient, and secondly, if possible, save the kidney."

### **Sequelae of Rupture of the Diaphragm**

Other effects of injury of the diaphragm include: (1) the lodgment of fragments of foreign bodies in the diaphragm itself; (2) diaphragmatic hernia; (3) scarring and adhesions.

The most dramatic of these sequelae is *diaphragmatic hernia*; this may develop immediately or soon after the injury; on the other hand symptoms are commonly delayed for several months or longer. Traumatic diaphragmatic hernia rarely produces symptoms on the right side, and at most contains only a small piece of omentum in that situation. Only very rarely does a rent occur between the abdomen and the pericardium. The left dome is that most often implicated, and the herniated viscera include the omentum, stomach, transverse colon and splenic flexure, spleen, and jejunum; it is stated that the pancreas, liver, and duodenum are only very rarely herniated.

Such cases are best operated upon by a thoracic approach; an incision is made in the eighth or ninth intercostal space; the resection of adjoining ribs may also be required. Positive-pressure anaesthesia is employed; the phrenic nerve is crushed as it lies upon the pericardium before entering the diaphragm. The extruded viscera are first separated from the edges of the diaphragmatic aperture and thoracic structures, and are then coaxed into the coelom.

The repair of the rent in the diaphragm may be difficult if the muscle has undergone fibrotic or atrophic changes. Strong silk is employed: in some cases fascial grafts seem to give greatest promise of permanent closure. In others the gap can only be closed by suture of the liver, spleen, or stomach to the margin of the opening. In cases of some duration the stomach may have undergone hypertrophy and dilatation, and a laparotomy may also be required to anchor it satisfactorily inside the abdomen. The performance of a temporary gastrostomy in some such cases has proved of inestimable value in my hands. The complication of *strangulation* in connexion with a *diaphragmatic hernia* is fraught with the grav-



est peril The colon is the segment of the alimentary canal most frequently obstructed, sometimes the jejunum is the part compressed, very rarely is the stomach strangled

A correct diagnosis is not often attained unless there is previous knowledge of the existence of a hernia, but where such knowledge is lacking an antecedent history of a severe injury in the abdomino thoracic zone, a previous complaint of post prandial discomfort and even dyspnoea hiccup, precordial oppression, and pain in the shoulder, together with the evidence of competent radiology, should enable a pre operative diagnosis to be made

The symptoms of strangulation usually supervene suddenly, the baleful results of operation for this disastrous complication constitute a powerful argument for early operation upon traumatic diaphragmatic hernia, at any rate if the symptoms to which it gives rise show any evidence of worsening The transthoracic approach should be employed

Familiarity with the transdiaphragmatic approach to the vault of the abdominal cavity has been turned to useful purpose by thoracic surgeons in the operation of cardio omentopexy (O Shaughnessy, J B Hunter) The successful operation by Pierre Duval (1918) for the extraction of a bullet from the suprahepatic portion of the inferior vena cava, in which the sternum was split and the diaphragm divided backwards to the caval opening still remains to my mind the most brilliant operation in the history of surgery

Even the general surgeon avails himself of an abdomino thoracic approach in operations for the surgical removal of malignant disease of the lower end of the oesophagus or the cardiac orifice of the stomach

No reference to the employment of the sulphonamide derivatives has been made in this communication, this is now a routine measure, and its value is incontestable The severe shock which appears so constant in wounds of the trunk in this war demands a bountiful supply of blood and plasma, which on occasion is preferably introduced rapidly into the veins of the recipient

In this war abdomino thoracic injuries due to fragments of high explosive are probably less grave than those due to crushing force or the effects of blast



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# BLAST AND CONCUSSION IN THE PRESENT WAR

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The first definition of a bomb in the *Oxford Dictionary* is "a ball of wilde fire". The Spaniards, it seems, quite early developed technics for burning enemy ships by projecting fire balls at their adversaries' sails and wooden decks, so that the first bombs were, strictly speaking, incendiaries. Later, mortars were developed for hurling explosive incendiaries. These explosive balls of fire became in the course of time less fiery and more highly explosive, and in the nineteenth century they came to be known as bombshells. By the end of that century and during the last war, bombshells became just shells, and the word 'bomb' was reserved for explosives dropped from the air—or from the pocket of a discontented agitator.

The Nazis were the first to develop air bombing technics on a large scale—not only bombs of the high explosive variety—screeching, bouncing and parachute bombs—but also "balls of wilde fire" in the form of incendiaries, many of them diabolically arranged so that, when a fire fighter attempts to smother them, they explode, showering hot burning magnesium in the faces of their victims. When attacking ships and objectives in England during the last two years, the Germans have used five types of high explosive shells, the 50 kilo, 250 kilo and 500 kilo aerial bombs and the 500 kilo and 1000 kilo land mines.

## Physical Characteristics of Bomb Destruction

The 50 kilo bomb, which has been used in such profusion over the London area, produces destruction within a sharply circumscribed space for a width of 20 to 25 feet in brick dwelling houses, such as one encounters on Commonwealth Avenue or Marlborough Street, Boston, and if one of these houses were struck, one might expect, if British example were followed, to see signs of "Business as Usual" on both sides of the 25 feet of gutted building. Similarly, when such a bomb strikes the middle of the street, it penetrates beneath the surface before exploding and then lifts up a heap of dirt over an area 20 to 30 feet in diameter and 3 to 5 feet in depth, depending on the character of the surface. The resulting crater presents a hazard to traffic. Taxicab drivers navigating in the blackout become accustomed to dropping into craters of this sort but are so skillful that they generally stop their cars when the back wheels are on the edge, quietly back out, and take another street. In England, bombing even of the 50 kilo variety is serious since



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the winters are mild, the essential services are buried to a depth of only 2 or 3 feet. Almost invariably, therefore, a bombing episode in the street results in interruption of all five services—water, gas, electricity, sewerage and telephone; however, the demolition squads work with incredible speed, and generally within ten or fifteen hours all the services are repaired and the streets repaved. But all this requires a close-knit organization on the part of a dozen agencies and utilities, and I should think that the sooner such an organization is worked out on the eastern seaboard of the United States, the less the inconveniences of bombing would be felt when the time comes for the enemy to strike. We have the rich experience of the English people at our disposal. We have seen their mistakes. We have seen their magnificent reorganization on the basis of those mistakes, and I can only hope that we may profit by them.

The 250-kilo bomb creates greater havoc, but again the area of destruction is sharply circumscribed, being limited to 100 to 130 feet of four-story brick construction; if the bomb strikes in the middle of the street, the crater is 75 to 100 feet in width and 8 to 10 feet in depth. Windows may be broken at considerable distances—up to 200 or 250 yards—from the blast wave.

The 500-kilo or 1000-pound bomb, of which, fortunately, the Germans have been able to use very few, is incredibly destructive and may, if it happens to strike favorably, demolish the greater part of a city block. The effects of the blast wave in the air and through ground-shock may topple buildings at a distance of several hundred yards, and the results of a given detonation of this size of bomb are as bizarre and unpredictable as they are destructive. Much the same thing may be said for the land mine, which, coming down by parachute, may destroy the greater part of a city block. No details concerning the so-called "super-bomb" that the British are now using are available, but it is evidently "super" in the sense of having greater weight; if it is true that the British are using bombs weighing 1 to 2 tons, the havoc wrought in closely built areas must be colossal.

#### **Blast Injuries**

The first detailed histologic study of the effects on the central nervous system of blast from high explosive shells is found in a paper by Mott,<sup>1</sup> which comprises the Lettsonian Lectures delivered before the Medical Society in London in February and March, 1916. During the Civil War, Mitchell, Morehouse and Keen<sup>2</sup> described the blast syndrome in unmistakable terms, but the neuron at that time was not an entity, since stain-



ing of the nervous system to aid in histologic scrutiny had scarcely begun. Mott draws attention to Sir Anthony Bowlby's<sup>3</sup> Bradshaw Lecture *Wounds in War* delivered in 1915 in which he remarks

It must also be kept in mind that the mere explosive force of the gases of a large shell exercises great powers of destruction. The expansion of the gases is alone sufficient to kill and in the only case in my experience in which an autopsy has been made the brain was the seat of very numerous petechial haemorrhages.

This brain which had been in Sir Arthur Keith's custody, was turned over in 1916 to Mott who confirmed the existence of widespread petechial hemorrhage but who also noted changes compatible with carbon monoxide poisoning. He cites in addition, several nonfatal cases in which the explosion of large shells caused loss of consciousness without visible external signs of injury. In all these cases the patient in question was propelled some distance by the blast wave but there were no external injuries to suggest a primary blow on the head. Two of these cases may be cited.

A lieutenant under my care told me that he was in a communication trench when an aerial torpedo exploded close to him. He felt a great pressure against him; it was soft but sufficiently powerful to knock him down unconscious. He did not know how long he was unconscious but thinks it must have been an hour. When he recovered consciousness he got up and was helped away. His head felt as if it would burst and ever since he has had a whizzing in the left ear and dizziness. Dreams of bombs and aerial torpedoes bursting. There was no parapet to blow down on him.

An R.A.M.C. officer at the battle of Ypres had a shell explode near him. He was not hit but lay unconscious for six hours. He recollects the shock of the shell as he went out of the dressing room. For some days he suffered with severe headache and soreness of back of head and down the spine; the lower extremities felt heavy but there was no loss of feeling. He had retention of urine for a day only and around the body there was a pain like an appendix pain. He rapidly recovered.

The first case is typical of hundreds of thousands in World War I. One must recall that men were engaged in trench warfare and that they were protected from shell fragments by keeping submerged in trenches but were not protected from the blast wave of a shell exploding in close proximity. On recovery those who were actually rendered unconscious by proximity to an exploding shell complained of headache, dizziness, lethargy and inability to concentrate—in short they exhibited all the major signs and symptoms of the postconcussion syndrome of peacetime. In the parlance of the early days of the last war they were said to be suffering from shell shock (von Sarbo<sup>4</sup>).

The problem of distinguishing psychogenic war neurosis from a case



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of organic concussion resulting from blast is delicate and often difficult, but I agree with Myers<sup>5</sup> that such a distinction is clearly essential. In a book recently published, he distinguishes between "shell concussion," a syndrome associated with organic injury to the brain, and "shell shock," a psychogenic syndrome due to the fears and fatigue of warfare. Often, however, the two syndromes are confused (Roubinovitch<sup>6</sup>).

It is interesting to trace the term "shell shock" in the various connotations that it acquired during World War I. Late in 1914 and during 1915, a soldier was said to have suffered shell shock when he was picked up unconscious and externally uninjured in the vicinity of an exploded shell. The usage was thus synonymous with "shell concussion." Stevenson,<sup>7</sup> however, in a short paper concerning the cause of death due to high-explosive shells in unwounded men, concluded that sudden death in these circumstances results from "concussion of the brain and interference with the functions of nerve centres which are essential to life, and the interruption of which means instant death." "I have seen many men," he continued, "home from the front who have been exposed to these explosions; all their symptoms and all their accounts of their experiences tend to confirm this belief, for it is to the less severe injuries to these centres that the symptoms of men who recover and come home all point." Later, shell shock came to be applied more particularly to the cases of functional war neurosis.

Stevenson also refers to the interesting speculation of the French civil engineer, Arnoux,<sup>8</sup> who observed an exploded aneroid in the pocket of a French officer who had been killed by proximity to an exploding shell. The aneroid was repaired, and it was found that a sudden compression of 10,000 kilos per square meter was essential to disrupt it. Arnoux put forward the theory that, following such compression, gases in the blood and tissues expanded with bubble formation, and that men were killed by sudden massive air embolism. The aneroid observation is interesting, but the attempt to explain death as due to bubble formation was far fetched, since it did not take into consideration the rate at which gases dissolve under pressure, and the slow rate at which resolution occurs when pressure is diminished.<sup>9</sup>

To Mott<sup>1</sup> must be given the credit for having first emphasized the significance and likelihood of carbon monoxide poisoning in the vicinity of an exploding shell, especially one exploding in a confined space. Oxygen is absorbed by the explosion, carbon monoxide is liberated, and many of the so-called "deaths from blast" have been shown to be due to carbon monoxide poisoning of persons unconscious or pinioned under debris. The importance of carbon monoxide poisoning has lately been re-emphasized in connection with bombing injuries among civilians in England and Germany. However this may be, death from primary blast is a clinical entity that requires close study, because of its intimate connection with concussion and with the postconcussion syndrome of neuropsychiatry.

The general subject of blast injuries is discussed under four headings: the physics of the blast wave, the effects of blast on animals, the effects of blast on man, and suggestions concerning therapy.



## Physics of Blast Wave

Bernal<sup>10</sup> of Cambridge England has given the best general account of the physical characteristics of a high explosive wave. In material of high density and small elasticity the wave travels slowly, where density is small and elasticity great as in air the wave travels at great speed. The high pressures created by bomb explosions cause an enormous velocity of wave transmission in air but the rate of movement diminishes

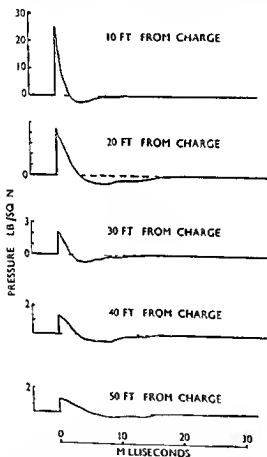


FIG 1—Figures Showing the Progress of a Blast Wave from a Small Charge of Powder (Bernal<sup>10</sup>)

rapidly as the wave proceeds and there is also a marked change in the shape of the wave as it progresses. The pressure in some waves rises immediately to its peak and then falls off gradually and is followed by a phase of less than atmospheric pressure that is the negative phase (Fig 1). The generation of this steep fronted wave is very similar to that of the waves that break on the seashore. The high pressure phase



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of the disturbance, which always travels faster than the low-pressure phase, gets to the front just as the top of a wave on the sea, being held back less than the base by the friction of the sand, moves forward and ultimately breaks the wave.

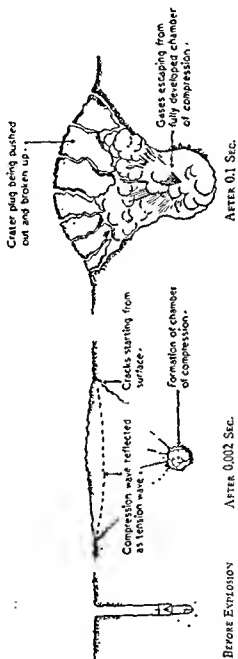


FIG. 2.—The Series of Events Accompanying a Bomb Explosion in the Earth (Bernal<sup>10</sup>).

This steep-fronted wave, sometimes known as the "shock wave," is responsible for blast and also for some of the bizarre effects of high



explosives, such as the smashing of windows and doors at a distance. Pressure values of 5 to 10 pounds per square inch will break most windows, but blast pressures must rise to 6 atmospheres, or 100 pounds per square inch, before endangering a human being. This means that, to be injured by primary blast, a human being must be very near the site of the explosion. Zuckerman's<sup>11</sup> data on animals suggest that, at a distance of 30 feet from a 50 kilo bomb, a human being would be entirely safe from the direct effects of blast, published data concerning individual bombing episodes in which blast injuries have occurred in man support this deduction. With the large bombs, such as the 250 kilo and 500 kilo ones the blast wave is more intense and travels farther.

Another aspect of bomb explosion concerns the blast wave in the earth, the so called ground shock. Dropped from a great height, bombs generally penetrate some distance into the earth, the depth varying with the character of the surface. As previously mentioned, a 50 kilo bomb makes a crater of 20 to 30 feet in a dirt road. The sequence of events has been diagrammatically indicated by Bernal<sup>10</sup> (Fig 2). A ground wave has a high velocity, with an abruptly rising wave that may cause buildings to be shaken down at some distance from the site of the explosion.

### Effects of Blast on Animals

The effects of primary air concussion due to shells or other explosives were not investigated experimentally until the end of World War I,<sup>12 15</sup> and to Hooker<sup>16</sup> must be given the credit for the most thorough experimental analysis as yet available. Men exposed to shell concussion, he pointed out, often developed a condition of shock that was unrelated to obvious trauma, since neither external nor internal wounds were clearly demonstrable. To investigate the phenomenon, a study was undertaken in the winter months of 1918-1919 at the Sandy Hook proving ground, with subsidy from the Committee on Shock of the National Research Council. In retrospect, it is highly significant and clearly a tribute to Hooker's insight that he regarded the condition of circulatory collapse following violent air concussion as indistinguishable from the circulatory collapse from primary shock that follows traumatic concussion in civil life. Hooker had opportunity to study the effects on frogs, cats and dogs with the animals placed at varying distances from the muzzle of 10 inch and 12 inch guns and also from direct trinitrotoluene detonations. One dog, for example, placed 4 feet from the explosion of 4 pounds of trinitrotoluene, exhibited a fall in systolic blood pressure from 114 to 74 mm., and a fall in venous pressure from 87 to 62 mm.



Hooker's studies emphasize four points: the fatal effects of primary blast occur in animals only relatively near the explosion, a difference of 2 or 3 feet often determining the question of life or death; there is a syndrome of primary shock characterized by collapse of the blood pressure in animals affected, but not killed, by the primary blast; there is complete absence of petechial hemorrhages or other intracranial lesions in the brains of animals exhibiting marked primary shock; and hemorrhagic lesions of the lungs and occasionally of other visceral organs are prevalent in animals subjected to blast. In his experience, however, the extent of the lung lesion bore little, if any, relation to the gravity of the concussion symptoms.

The experimental results of Hooker thus strongly suggest that the effects of primary blast in animals are closely similar to the effects of a blow on the head in an otherwise normal animal. He drew attention to the experimental studies of Githens and Meltzer,<sup>17</sup> and raised the question, without committing himself to an answer, whether the symptoms of air concussion were not ultimately similar to traumatic cerebral concussion.

Hooker's studies were published in 1924, but they aroused little comment. In the clinical literature during and after the war, there were many discussions of shell shock as an entity, and some authors, as already mentioned, used the term "shell concussion" to characterize symptoms resulting from primary blast.

New light on the problem has come from two groups of studies, one on blast and the other on experimental traumatic concussion of the head.

*Primary blast.* Zuckerman<sup>11 18</sup> has given two detailed reports on the effects of primary blast in different animals, including mice, rats, guinea pigs, rabbits, cats, monkeys and pigeons. Seventy pounds of a high-explosive charge in paper containers so arranged that there would be no danger of injury from flying missiles was used as the source of the blast wave, and animals placed in well-anchored wire-mesh cages were arranged at varying distances from the charge. As in the experiments of Hooker, there proved to be critical distance zones, which varied with the species of animal, monkeys being considerably more resistant, for example, than rabbits. No monkeys were killed by a 70-pound charge at distances greater than 18 feet, and in no animal, rabbits included, were effects detectable at distances greater than 50 feet, at which the positive component of the blast wave averaged 6.3 pounds per square inch. Between 13 and 18 feet, almost all animals were killed when so placed that their body walls were affected by hydrostatic pressure alone.



At these distances, the positive component of the blast wave, that is, the hydrostatic pressure, varied between 126 and 63 pounds per square inch

Between about 20 and 50 feet, no animals were killed, and those that survived showed little change in behavior. Those surviving between 18 and 21 feet often died within a few minutes to twenty four hours after the blast, they exhibited widespread pathologic changes, the most conspicuous as in Hooker's experiments, being hemorrhagic lesions of the lungs. But also as in Hooker's experiment, there seemed to be no clear relation between the extent of the pulmonary lesions and the degree to which the animal had been affected by the blast wave. The pulmonary lesions are well illustrated in Zuckerman's<sup>18 19</sup> later report.

Lesions were also found in other organs, including the epicardium of the heart, and very frequently in the large intestine, which proved to be the most susceptible, next to the lungs, to the effects of blast. The lungs, spleen and kidneys were often bruised or lacerated.

The nervous system was also carefully observed, especially in monkeys, the sections having been studied by Greenfield and also by Clark. The more important findings are summarized as follows<sup>18</sup>

No changes were observed in the cortex, mid brain, pons or medulla of monkeys subjected to pressures as high as 110 lb per square inch. On the other hand most monkeys exposed to high pressures show extradural haemorrhages in the thoracic spinal roots, which are sometimes continuous with haemorrhage along the intercostal nerves. In two animals that died, haemorrhage had occurred at the central ends of the posterior columns, and in the dorsal commissure. Furthermore most animals have shown a zone of oedema, absent in controls, around the central canal especially in the thoracic region but also in the cervical and lumbar cord. This oedema may involve both anterior and posterior commissural fibres.

Changes in nervous tissue are more pronounced in rabbits exposed to high pressures. Pial haemorrhages occur on the surface of the cortex, and haemorrhage from the tela choroidea, filling the ventricles, has been observed. Haemorrhages have not been seen however, in either the grey or white matter of the brain.

Spinal cord haemorrhages (in rabbits) are of the same kind as, but more severe than (those) in the monkey.

It is conceivable that as a result of these lesions the sympathetic outflow may be interrupted and that sensory defects may occur as a result of oedema and pressure on the commissures.

Stewart, Russel and Cone<sup>20</sup> report on injuries to the central nervous system of a pheasant by blast during an air raid. The blasted pheasant was found 90 feet from the edge of a bomb crater, dazed and paretic after two large bombs had been dropped, but there was no way of determining how near the bird had been to the actual site of the ex-



plosion. It was in a catatonic state, and tended to retain any attitude in which it was passively placed. Microscopic examination of the nervous system showed congested capillaries of the forebrain, associated with numerous petechial hemorrhages, which were most numerous in the hypothalamic area. There were also massive hemorrhages in both lungs and numerous small hemorrhages in the heart. The report of Stewart and his co-workers is essentially in harmony with that of Zuckerman for the more serious cases of blast injury, but Zuckerman and Hooker insist that conspicuous symptoms referable to the nervous system may often be found with little recognizable histologic change.

*Concussion.* In previous experiments on concussion, such as the excellent studies of Pilcher,<sup>21</sup> Schaller et al.<sup>22</sup> and Scott,<sup>23</sup> measured blows were delivered to an animal whose head was rigidly fixed; since anesthesia was employed, one criteria of concussion, namely, loss of consciousness, could not be appraised. The following clinical experience of Denny-Brown<sup>24</sup> suggested that acceleration of the head in space was essential for the concussion syndrome, rather than a blow on the head per se. An automobile mechanic, when his head was solidly on the concrete floor, had the misfortune to have a car fall off the jack, and his head was pinioned against the floor by the car's differential. He suffered a severe compound fracture, but no symptoms of concussion; indeed, immediately after the accident, the man was unaware that he was seriously injured. In this case, there had been no movement of the head, merely a crushing blow. Similar cases have just been reported by Eden and Turner.<sup>25</sup> If, however, the head is struck when unsupported and is thus able to move, symptoms of concussion inevitably develop. Furthermore, if the head, when moving, is brought abruptly to a stop, deceleration occurs and is similarly effective in producing concussion. On the basis of this reasoning, Denny-Brown and Russell<sup>24</sup> devised a series of experiments in which a fixed head was struck with a pendulum moving at velocities between 10 and 30 feet per second, the results being compared with those obtained with similar blows when the head was free to move. With the head fixed, blows that gave severe contusion and fractures of the skull failed to cause concussion. With the free head, three categories of symptoms developed, depending on the intensity of the blow, and usually appeared in the following sequence: shock, concussion and contusion.

*Shock.* When the blow is delivered at about 23 to 24 feet per second, the animal develops the classic symptoms of traumatic shock. The pulse rate slows for a time and then increases, the blood pressure falls, respirations become quick and shallow, and the animal becomes incapacitated for a period of several hours:



but the knee jerks and the pinnal and corneal reflexes are unaffected. It is highly significant, especially in view of Hooker's<sup>10</sup> and Zuckerman's<sup>18 19</sup> work on blast that a blow on the head can of itself induce symptoms of generalized shock.

**Concussion.** A distinction is made between shock, as such, and symptoms of concussion which develop when slightly heavier blows are delivered, that is, those struck at a velocity of 25 to 28 feet per second. Following these heavier blows the corneal and pinnal reflexes are abolished for varying intervals, the resting posture (tonus) of the extensors disappears, and spinal reflexes may be altered or even temporarily abolished. A blow of this magnitude, if delivered to a conscious animal renders it unconscious, whereas the blow causing shock does not necessarily cause unconsciousness.

The pathologic changes in the brain associated with shock and concussion blows have been carefully sought and have been proved wholly absent so far as ordinary microscopic examination is concerned. There are no petechial hemorrhages and no contused hemorrhagic areas in the medulla or cerebral hemispheres. The microscopic causes of the symptoms of concussion are still obscure, but no doubt they involve some basic intracellular disorganization of the neuron.

**Contusion.** When blows are delivered to the head at a rate greater than 28 feet per second contusions usually develop in which hemorrhages occur beneath the site of the blow (or as a contrecoup at the opposite side of the head), and petechial hemorrhages are prone to develop especially in the basal nuclei, brain stem and medulla. Age and other factors, however, affect the actual velocity essential for contusion.

The studies of Denny Brown and Russell thus indicate that conspicuous concussion may be produced in animals without causing clearcut histologic changes. Studies of Hooker<sup>10</sup> and Zuckerman<sup>11</sup> prove that this is also true of blast concussion. Is there anything in common between direct traumatic concussion and blast concussion?

Zuckerman<sup>18 19</sup> is of the opinion that lung damage is due to the physical impact of the blast wave against the thoracic wall rather than to sudden distention of the lungs by the positive component of the blast wave, or to a suction effect of the negative component of the blast wave. Such changes as occur in the central nervous system are likewise thought to be caused by sudden impact. There are obviously two components to be considered in the blast wave: the primary increase in atmospheric pressure to 100 pounds or more per square inch, and the rate of movement of the blast wave itself. Sudden increase of pressure might rupture the tympanic membrane, but from experience of caisson workers it is not likely that the pressure itself would cause concussion any more than a mechanical blow on a fixed head. A wave of moving pressure that gives acceleration of the body by virtue of its impact on the body wall—and hence imparts an acceleration to the body as a whole, including the head—reproduces in a very precise manner the type of acceleration or deceleration known to be essential for the traumatic concussion syndrome.



## *Blast and Concussion in the Present War*

Those who are surprised by the apparent lack of histologic change in cases of concussion will be interested to learn that de Gutierrez-Mahoney,<sup>26</sup> of Nashville, Tennessee, has confirmed the results of Denny-Brown and Russell, finding that when the fixed head is struck there is in fact no detectable histologic change, but that when the head is given an acceleration by a corresponding blow and concussion results, a widespread demyelination of nerve tracts, followed by a transient appearance of fat droplets throughout the cerebral substance, can be detected; outspoken fat embolism may also result. The fat droplets and emboli tend to disappear entirely within three or four hours after the blow, and de Gutierrez-Mahoney believes this to be the reason why fat embolism has not been previously demonstrated.

Fat embolism has assumed prominence in the present war, and there are many reports in the current literature, especially from England, concerning its incidence. In a group of 115 cases reported by Robb-Smith<sup>27</sup> in February, 1941, death was attributed to embolism in 25 per cent of cases. In a more recent discussion on fat embolism and the brain, Robb-Smith<sup>28</sup> and others who contributed to the discussion suggest that cerebral complications developing secondarily after an accident are due to the fat emboli that have passed through the lungs into the cerebral circulation. These may arise locally in contused tissues, such as a crushed long bone. Usually, the lungs separate out all the fat globules, but occasionally a pulmonary vein is torn so as to permit escape of fat into the systemic circulation. Robb-Smith states: "In systemic fat embolism the symptoms usually develop two to three days after the accident and are characterized first by delirium, which is frequently very violent, alternating with stupor which merges into coma. Localizing signs are usually absent or, if present, are chaotic. Hyperpyrexia is usual and it is not uncommon to find petechial haemorrhages in the skin of the neck, chest and arms, and their presence greatly facilitates diagnosis." He had not encountered cases in which cerebral fat embolism was attributable to direct traumatic concussion of the head.

### **Effects of Blast on Man**

High-explosive bombs and shells have been used more widely on civilian populations and at sea during World War II than in any previous conflict. When bombs or shells explode in a confined space, as in a building or on a ship, the blast effects are many times intensified. There is thus no more urgent problem connected with the present war than the analysis of blast and its effect on the human body. Despite this, available literature is scant, and research endeavor has been limited to a small group of investigators in England, who took up the problem to help in designing adequate air-raid shelters for protection from blast,<sup>29</sup> as well as from high-velocity fragments. Although this country has for two years been aware of the bombing of cities and shelling of ships on the high seas, nothing has been done toward investigating blast.



From English sources, especially from the reports of Dean, Thomas and Allison,<sup>30</sup> Ialla,<sup>41</sup> Hadfield and his co workers,<sup>7</sup> Hadfield and Christie,<sup>41</sup> Kretschmar,<sup>42</sup> Krohn,<sup>43</sup> Logan<sup>2</sup> and Thomson,<sup>47</sup> it is believed that death from uncomplicated primary blast in civilian areas is rare, but well authenticated cases have been reported, especially in the recent and well documented account of 17 cases by O'Reilly and Gloyne.<sup>35</sup> Uncomplicated cases of primary blast may, however, be relatively uncommon since to be killed by its effects, the person must be very close to the explosion—that is, within 20 or 30 feet (50 kilo bomb). In these circumstances, the chances of being struck by the blast wave alone and not by splinters is somewhat remote. But there have been many thousands of cases in which primary blast and splinter injuries have coexisted. These have been especially common when a direct hit has been made on a crowded air raid shelter. Similar episodes have occurred at sea,—in the shelling of crowded transports and warships,—and primary blast should therefore always be suspected in any bombing injury.

The histologic findings in man, so far as they have been described, are similar to those in Zuckerman's<sup>18</sup> monkeys subjected to blast waves of 100 pounds per square inch namely, pulmonary hemorrhages, contusions and lacerations of other thoracic and abdominal viscera, minor changes in the central nervous system and occasional areas of subpial hemorrhage.<sup>38</sup> Evidently, as in animals, profound concussion can occur with little in the way of histologic effect.<sup>39</sup> Whether acute cerebral fat embolism exists in such cases has not been determined.<sup>40, 47</sup>

### Therapy

It is not possible to discuss the difficult problems of therapy in cases of cerebral and pulmonary concussion resulting from primary blast, but one general principle is clear. As more is learned about traumatic concussion in civil life, as well as concussion from blast, it becomes obvious that anoxia plays a large role in the total picture. Blood pressure tends to fall as a result of primary shock.<sup>24</sup> The recent German literature<sup>43</sup> on cerebral blood flow following concussion, moreover, indicates that cerebral circulation becomes diminished, and that the pulmonary damage is frequently accompanied by fat embolism. All these circumstances, in my opinion indicate the need for oxygen therapy, and for measures designed to improve the systemic and especially the cerebral circulation.<sup>44</sup>

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# LUNG INJURY DUE TO THE DETONATION OF HIGH EXPLOSIVE

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To the neutral observer this war is truly different from previous struggles; different in its conception of attack and defense, as well as in the vulnerability of the civilian population. As a result of the development of the bombing attack, attention has been directed to new problems of war injury. Numerous reports have appeared concerning the effects of detonation of high explosive. And attention has been called to the fact that many deaths occur without evident gross injury to the body, while the necropsy reveals varying degrees of trauma to the lung. Many clinical and experimental studies have been made on the differing types of injury due to "blast" and the results appear to have given rise to varying conclusions. Moreover, in recent discussion appearing in the American literature little or no attention has been directed to this form of lung injury. It is, therefore, the purpose of this discussion to review critically the recent clinical and experimental studies that have been made on the effects of detonation of high explosive, particularly on the pulmonary system, and to compare them so far as possible with the "similar" forms of lung injury as observed in peacetime civilian life.

## Peacetime Injuries to the Lung

Lung injury in the intact thorax, apart from a few isolated cases, has received but little mention in the English surgical literature. Its occurrence was recognized and described as early as 1761, when Morgagni reported two postmortem findings. Richter, in 1904, and Schwartz and Dreyfus in 1907, each gave a good account and a review of the current literature, and Fischer wrote an excellent monograph in 1912.

Thoracic injuries are to a certain extent comparable with those of the abdomen and skull in that attention is devoted less to the parietal lesion than to the possibilities and extent of damage to the contained viscera (Smith, 1840; Sellors, 1933). Many of the cases reported were the result of severe crushing violence to the chest and the diagnosis was not usually made until postmortem examination.

*Physiological anatomy of the thorax.* Most writers are agreed that injury to the thoracic viscera is more frequent in children and adolescents and that this is resultant to the elastic nature of the juvenile thoracic cage.



It has been suggested that the lung is simply compressed between the more resilient ribs or against the vertebral column.

In a series of experiments on the thorax after removal of the contained viscera, Triepel (1902) made the interesting observation that the male thorax can withstand more lateral and the female more sagittal pressure. Kulbs (1909), in his animal experiments, found that the chest



FIG. 1. Gross appearance of the lung after injury by contusion in peacetime civilian life. Note the scattered areas of hemorrhage.

yields more to a blow from the front and, as a whole, is less capable of resistance to this injury. Compression of the thoracic cage, according to Limón and Pera (1921) causes immediate diminution in its size, primarily at the expense of the mobility of the costovertebral and costosternal joints. When the motility of these joints is insufficient, a new factor intervenes which is determined by the elastic properties of the costocartilaginous cage.



## *Lung Injury Due to the Detonation of High Explosive*

The presence of air within the lung at the time of injury was discussed by Gosslin (1845), Gross (1866), LeConte (1908) and Adams (1933). It was pointed out that sudden compression of the air within the lung causes the lung to rupture owing to the resultant instinctive closure of the glottis, together with the withholding of breathing, thus making it impossible for the pulmonary sponge to empty.

Peyrot (1907) stresses the anatomicophysiological arrangement of the pleura. The normal cohesion of the pleural surfaces holds the lung to the parietes. Thus, if the chest wall with its parietal pleura and the lung with its visceral pleura are depressed, the remainder of the lung is prevented by its natural adherence to the chest wall from following the movement. A part of the organ which is seldom stretched is thereby put under tension and tears may result.

Du Sèjour (1901) agrees that the mechanism stressed by Peyrot would explain rupture if the pleura were adherent, but thinks otherwise, that there is too much gliding between the pleural surfaces. In his opinion the air-filled lung is abruptly compressed at the time of trauma and escape of the air through the upper air passage is insufficient. Hence rupture results by sudden compression as one might burst an inflated paper bag. Similar opinion was expressed by Gross (1866).

Joannides and Tsoulos (1930), after experimental work on the production of mediastinal emphysema in dogs, came to the conclusion that "anything which produces an increased intrapulmonary pressure, such as a severe cough, the labor of childbirth, lifting of a heavy weight, etc., probably causes a mild degree of mediastinal emphysema and air embolism, which as yet we have no way of recognizing clinically."

*Morbid anatomy after injuries.* The morbid anatomy of the injuries varies greatly. In simple contusion, bleeding occurs into the lung substance, as Duval (1918) has shown, producing areas of contusion at the base and apex of the injured lung, with blood infiltration of varying extent—simple contusion by *contre-coup*. Duval even demonstrated small tears of the visceral pleura on the opposite side.

Rupture of the alveoli with interstitial emphysema about the capillary vessels was also noted recently in the animal experiments of Adams (1933) carried out by simulating a submarine escape. Sometimes the hemorrhage is severe and may be localized to one lobe as in an instance reported by Sauerbruch (1937). It can be even more marked, as in the case of Rocher and Dupérié (1927) which is typical of gross hemorrhagic infiltration of both lungs without apparent tears in the pleura. Similar observations were also reported by Duval.

Fischer (1912) gave an anatomical classification of rupture of the



lung according to the severity and site of the lesion (1) Crushing into a shapeless mass of one lobe of the lung or of the whole lung, (2) internal rupture of the lung with intact visceral pleura, (3) complete penetrating rupture of the lung, (4) separation of one lobe of the lung

Cooke (1936) more recently presented a clinical classification of pulmonary injuries (1) the pneumothorax type, (2) parenchymal rupture—this is a simple rupture without laceration of the visceral pleura (3) combined types

Tears of the larger bronchi are known to occur (Davis 1891), and are compatible with life provided the patient survive the immediate effects of the injury (Davies 1930 Clerf 1940)

Lung injury without trauma to the thoracic cage may be produced by the following causes (1) Run over by a heavy vehicle—accounts for 22 out of 70 cases in Fischer's series—Watson, Smith, Tatum, Johnson Harlan McDonnell, Ashhurst, Laurent, Kerr, Mercade, Richter LeConte, Villegas Sauerbruch, (2) blow on the chest—Davies, Bogdan Spiers Payne, Scott Connolly, Dieffenbach Head Gallon, (3) fall from a height—Gosselin Gross Wharry, MacTaggart, (4) lifting a child by the arms—Cockle (5) glancing blow of a bullet—Rees, (6) increase in the intrapulmonary pressure by coughing—Stransky, Sauerbruch during parturition—Cunnington dyspnea during tracheotomy—Werwath violent respiratory effort—Waters (7) nearby explosion—Delacroix Ravaut Thomas Sencert

### Illustrative Case Report

An example of this type of injury from our own records is presented as follows

Autopsy No 1238 1581 (Arch 1097) White boy aged 12 years The history relates that he was playing with two other boys at the city gravel pit They built a cave in the side of some loose shale The roof suddenly caved in and the boy sustained a heavy crushing blow on the chest by large pieces of falling shale and loose earth When dug out he was found bleeding from the nose and was brought immediately to the hospital He was pronounced dead upon reaching the hospital

On examination blood was found in the ears nose and mouth No other abnormality was found The clinical diagnosis was fracture of the skull

Postmortem examination revealed fracture of the base of the skull The left lung weighed 350 grams The pleura was unusually hemorrhagic The lung was expanded and many small haemorrhagic spots appeared scattered over its pleural surface On its cut surface appeared numerous areas of petechial hemorrhage The bronchi were filled with foamy blood The right lung presented identical changes (Fig 1)

Microscopic examination of the lungs revealed multiple areas of hemorrhage of varying size scattered throughout the entire lung Many of the alveoli



### *Lung Injury Due to the Detonation of High Explosive*

appeared disrupted and filled with red blood cells. The bronchi and bronchioles were also filled with red blood cells (Fig. 2).

This is an instance of peacetime injury of the lung without evidence of external injury. It was not recognized clinically. The fact that extensive visceral damage can be produced without revealing any *external* evidence is important from many points of view. The clinical significance of this example is obvious and has been recognized by certain surgeons.

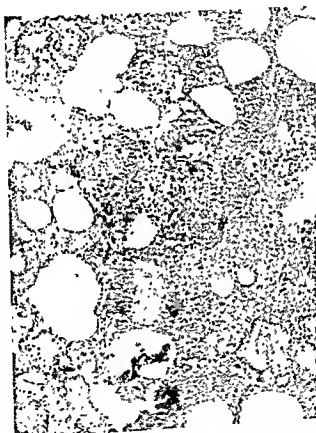


FIG. 2. Photomicrograph of the lung appearing in Figure 1. Note the hemorrhagic exudate in the ruptured alveolar spaces.

### **The Nature of High Explosive Effects**

Having reviewed traumatic lung injuries without external lesion as they are encountered in peacetime civilian life, it remains to compare them with the lesions produced by the detonation of high explosive. Many have a vague knowledge of the nature of explosives. This doubtless explains their ready acceptance of fantastic stories of the discovery



of explosives of extraordinary power, tales of which are so often circulated

Explosion has been defined as the act of exploding, a rapid combustion, decomposition or similar process resulting in a great and sudden development of gases and consequent violent increase of pressure, usually causing a loud report

Explosive is any substance that may cause an explosion by sudden combustion or decomposition. Two categories are recognized, low and high explosives. Low explosives are those having explosion velocities of a few thousand feet per second or less. Members of this group are characterized by a comparatively slow push type of explosive effect. High explosives are those having explosion velocities of from 5,000 to 25,000 feet per second and consequently, have quite a different effect. The violence of their detonation produces an extreme shattering effect in the immediate vicinity.

Detonation is a violent explosion one resulting from practically instantaneous decomposition or combustion of unstable compounds.

A bomb has been defined as a hollow projectile of iron, generally spherical containing an explosive material which is fired by concussion or by a time fuse also any similar receptacle of any shape containing an explosive as a dynamite bomb (Muehlberger, 1937).

The British speak and write of the immediate effect of the detonation of a modern high explosive bomb as blast.

*The chemistry of high explosive* High explosives depend for their action upon the instability of the chemical equilibrium of their constituents. They consist of compounds of carbon oxygen nitrogen and hydrogen so feebly combined that when fired by combustion or detonation new, simpler and more stable gaseous compounds are formed. Once chemical action is started it proceeds with great velocity and the explosive is immediately converted into gases with the evolution of heat. These gases now occupying an enormously greater volume than the original substance have powerful disintegrating properties. High explosives are violent, detonating at the rate of several miles per second, many times greater than the speed of the most violent hurricane (Bloxam 1882, Logan 1939, Storm 1939).

*The nature of "blast"* By blast or explosion is further designated the compression and subsequent suction wave which is set up by the detonation of high explosive. At every point in the immediate neighborhood there occurs first a momentary wave of high pressure (for about 0.006 seconds for a 70 pound charge) and then a negative 'suction' pressure due to the fact that the positive compression wave has reduced



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the density of the air behind it to below normal atmospheric pressure. Like the pressure component, the suction component of the blast wave lasts but for a fraction of a second, yet as a rule for a longer period than the compression wave (up to 0.03 seconds for a 70 pound charge).

The wave of pressure is highest in the immediate region of the explosion and falls off rapidly as it moves away. Thus 15 feet from a 125 pound charge, the hydrostatic pressure may be of the order of 200 pounds per square inch, whereas 50 feet away the maximum pressure recorded will not be more than 10 pounds. Everything in the immediate neighborhood of the explosion of a big bomb will therefore be suddenly exposed to a violent pressure wave of many times atmospheric pressure, whereas everything 50 feet away will be exposed to only two or three atmospheres of pressure.

The suction component of the blast wave is always weaker than the pressure component and in no case can it be greater than 15 pounds per square inch, since this corresponds to a complete vacuum. The magnitude of the pressure and suction components of a blast wave are correlated directly with the amount of explosive and are much higher for larger than for smaller amounts (Roomary, 1910; Taylor, 1932; Zuckerman, 1940).

*The physics of "blast."* The prime characteristic of any form of wave motion is that whereas the disturbance itself moves forward, the particles of the medium through which it passes do not move with it, but oscillate backward and forward about the position of equilibrium. The plane of oscillation may either cross the line of propagation, called transverse waves, or parallel the line of propagation, called longitudinal waves.

For the sake of simplicity imagine that the origin of the blast is a small sphere of explosive material. When this is detonated it expands suddenly and compresses a spherical shell of air immediately surrounding. Thus the blast wave consists of a compression followed by a rarefaction as it is propagated outward.

The maximum movement of any air particle on each side of its normal undisturbed position is called the amplitude of the wave and clearly depends upon the violence of the explosion. In the case of aerial bomb explosions such as are now being experienced in Europe, the amplitudes are considerable, for in the compression part of the wave pressure up to 200 atmospheres—that is, 1 and  $\frac{1}{2}$  tons per square inch—have been observed.

The phrase "beating the air" is commonly used to denote ineffectiveness. Beating the air is normally ineffective, because the mobility of



the air generally makes it easy for it to escape around the edges of the vulnerable object. The more sudden and violent the 'beating' the less is this true, and the more will the air act not like a mobile gas but a rigid object, so that the violence of blast can even bruise the walls of the lung as if they had been hit by a solid object (Berthelot, 1885, Burlot 1931, Sutherland, 1940)

### **The Effects of Detonation of High Explosive**

The extraordinarily varied effects of bombing on buildings in cities and towns have been vividly described and minutely detailed by Haldane (1938), Langdon Davies (1939), and others from their experiences in the Spanish War. They described how, when bombs burst in a street, the metal shutters of the shops which had not been hit were sucked out ward. When a bomb exploded inside a house a large part of the shattered walls fell inward.

According to Logan (1939), Zuckerman (1940) and others, a man may be wounded by a bomb explosion either by being hit by fragments of the bomb casing or by masonry or some other hard substance falling or sent flying by the explosion, or by being violently thrown, or by being affected by the blast wave without being thrown.

Lockwood (1940), and Logan reported that during World War I (1914-1918), men were sometimes picked up in the field dead from an explosion without revealing any external injury, and sometimes with blood stained fluid trickling from the nose or mouth. Similar experiences were described by Mogena (1938), Langdon Davies (1939), and Mit chiner and Cowell (1939), in the Spanish War.

Again in this war there have been reports of the damaging effects of blast on domestic animals. The damage to the lungs, characterized by alveolar rupture and hemorrhage, has been the consistent and dominant feature.

### **Clinical Investigation**

*Early observations* The literature on this subject is limited because this form of injury was not well known prior to the last war (1914-1918). Nevertheless the earlier clinical observations had led to the belief that the lesions and death from the explosive effect were due either to gases such as carbon monoxide produced from the detonation of the explosive (Brouardel, 1887, Cénas, 1887, Dujol, 1887, Serval, 1887, Mitchell, 1897, Urie, 1904, Bahier, 1905, Fabre 1906, Hatton 1911), or resultant to a sudden vacuum effect in those parts of the body which contain gas, e.g. the lung lobules, stomach, or intestine. Thus,



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experimentally, gas bubbles may be set free in the blood by the sudden evacuation of a chamber in which an animal is placed. These bubbles may then block the circulation as in compressed air workers or deep sea divers when they are too rapidly decompressed (Bert, 1875; Granjon-Rozet, 1877; Gaudin, 1887; Guinand, 1887; Reynaud, 1887; Thomas, 1917; Hill, 1917).

The earlier clinical observers also reported that this form of trauma produces injuries in the nervous system (Hinchcliff, 1875; Coskery, 1877; Duret, 1877; Michel, 1878; Tryon, 1891; Matignon, 1907; Zangger, 1907; Querleux, 1908; Etonensis, 1909; Llewellyn, 1910; Stierlin, 1912; Claude, 1914; Laurès, 1915) and in the lung (Reynaud, 1887; Paucot, 1901; Delacroix, 1907; Ravaut, 1915; Thomas, 1915; and Sencert, 1915).

*Recent observations.* Gatti (1918) presents a case of acute paralysis with subsequent atrophy following the explosion of a large bomb without actual contact. The condition was similar to that seen in anterior poliomyelitis and the assumption is made that the concussion injured the motor portion of the spinal cord. Similarly Cramer (1919) reports the case of a young soldier who presented the signs of a severe aortic insufficiency after being thrown several feet into the air by the explosion of a bomb. This patient had previously been healthy and had not had those diseases which might predispose to such a heart lesion.

Mott (1916, 1917) reported several patients as having died of explosive concussions in which two outstanding lesions were observed. First, the hematomas present in the lung, and second, the extreme vascular injury to the brain. He believed that the enormous aerial compression "may be transmitted to the fluid about the base of the brain and cause shock to the vital centers of the floor of the fourth ventricle, causing instantaneous arrest of the function of the cardiac and respiratory centers." This, he held, explained many of the instances of sudden death in which no visible injuries to the body were evident. Similarly Haldane, in describing a personal experience of his own during World War I when he was in the vicinity of bursting shells, thought that death under such conditions might be due to respiratory paralysis. Other similar observations of injury to the nervous system from the effect of explosion were also reported by Chavigny (1916), McWalter (1916), D'Abuno (1916), Meige (1916), Littermitte (1917), Pachantoni, (1917), and Marage (1918).

Mogena (1938) saw several instances of soldiers in Spain suffering from violent "bodily commotion" from proximity to a bursting shell. Examination of those killed by explosion (without obvious external injury) may reveal a tear of the lung, or a bulbar hemorrhage: in



others who live for a time rupture of meningeal vessels, hemorrhage from intestinal laceration and other internal trauma. In some the hemorrhage might not appear for 2 to 3 days. The author explains this as due in his opinion to gas embolism from sudden atmospheric decompression.

Falla (1940) reported a case with capillary hemorrhage in both lungs due to blast. The patient died 12 hours following operative intervention for bleeding from a laceration of the thigh after the use of open ether anesthesia (Fig 3).



FIG 3 Photomicrograph of the lung of a man who died as a result of injury sustained in an air raid (Fallas case). The alveoli which are disrupted are filled with blood cells (After Zuckerman)

Dean and Allison (1940) observed 27 instances and in all but two evidence of serious or gross pathological changes in the chest was absent. They called attention to the relative disproportion in frequency between the symptoms and physical signs in the cases studied: the frequency of a ballooned appearance of the chest and the radiological appearance of a diminution of rib expansion. A similar observation was made by Rose (1940).

Roberts (1940) pointed out the contraindication to surgical operation. Of two patients whose abdomens had been opened for intense



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abdominal symptoms, neither presented any demonstrable lesion and the thoracic injury appeared to be the real cause. He calls attention to the fact that if a group of bomb casualties contains one blast case it probably also contains others, even though the signs and symptoms are lacking.

Hadfield et al. (1940) reported 10 cases of sudden death in persons subject to the blast effect of high explosive bombs. In none of these was there any evidence of external trauma. There were gross hemorrhagic lesions in both lungs in all, and blood stained secretions in the upper air passages in some. Again they reported a case in which a man aged 23 lived for 51 hours after exposure to a blast. As a result of this observation they believe that patients who develop pulmonary hemorrhage without external trauma to the thoracic wall continue to bleed into the lung for a period which may amount even to 48 hours. In the light of the post-mortem finding of continued bleeding they concluded that these patients should be rested as strictly as if they had had recent severe hemoptysis (Fig. 4).

O'Reilly (1941) stated that from 3 cases which he had studied one clinical point had emerged; that within 48 hours in 2 and within 4 days in the other the clinical findings of an ordinary lobar pneumonia had apparently developed. Again 5 patients belonging to the same "incident" were brought in with the appearance of acute abdominal catastrophe—rigid abdomen, pain, and so on. Two were sufficiently serious to require surgical intervention, but nothing was found except a few minute subserous hemorrhages.

Ross (1941) made a comparative postmortem study of peacetime and wartime lung injuries and concluded that the main points of difference may be summarized as follows:

1. In compression asphyxia the lesions may be symmetrical on both sides but not necessarily. The hemorrhages are usually subpleural and in the lines of the ribs. There is generalized pulmonary congestion.

2. In hemorrhage due to impact of a solid the hemorrhage is in relation to the point of maximum impact and may be unilateral. The lung tissue is contused, torn, and filled with blood at or around this point.

3. In "hemorrhagic concussion" (due to blast) the lesions are always bilateral and roughly symmetrical. There is general congestion of the lung. Pleural hemorrhages are present only as an extension from deeper areas.

Osborn (1941) from the results of his comparative study of peace and wartime injuries to the lungs states that there are two forces which



bring about the the capillary hemorrhage in 'hemorrhagic concussion'. These are compression of the lungs through the chest wall and diaphragm and the counterpressure exerted by the air in the alveoli. The actual lesion is mainly hemorrhagic from the alveolar capillaries. The lesion itself is not progressive, as Hadfield et al claim, but the reaction is. Treatment is largely in the anticipation of complications.



FIG 4 Cut surface of the lung of a girl found dead in a public shelter which received a direct hit by an aerial bomb. Note the distribution of the hemorrhages which are most extensive in the deeper parts (After Hadfield et al)

In conclusion he states that "to understand the lesions described for blast in animals and men there is no need to assume that blast has any mysterious properties. It is only a more severe diffuse sudden com



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pression of the chest and abdomen than we see in civil cases during peacetime."

Robb-Smith (1941) after the study of 789 consecutive accident cases of all types again called attention to the fact that "the pulmonary symptoms which arise from exposure to the blast of high explosive may be due to a combination of pulmonary concussion and fat embolism, and fat emboli should be specifically looked for in autopsies on air raid casualties." A similar observation was also reported by McKibben (1919) from his experimental study.

*Experimental observations.* The prevailing idea formerly was that the nervous system was especially sensitive to this form of trauma. This received the support of Mott and others. However, clinical and post-mortem observations have now established that the pulmonary lesions predominate.

Carver and Dinsley (1919) report experiments on fish, rats, and mice. They state that the animals which were more exposed to detonation showed hemorrhages from the ears, nose, and mouth and when sacrificed exhibited varying degrees of internal hemorrhage in the viscera and central nervous system while the alveoli of the lungs were nearly always found to a certain extent ruptured.

Mairet and Durante (1919) have published several reports concerning concussion shock, the last of which presents their conclusions and opinions based upon a considerable amount of experimental work. They exposed rabbits to the detonation of high explosive under various conditions and made a particular study of the resultant lesions. The symptomatic behavior of the animals was also noted. The viscera of the animals at necropsy were found to be normal except for the lungs which were spotted with hemorrhagic areas. On the surface of the cord in all cases they found varying amounts of blood suffusion, irregularly distributed, with small clots adhering to the nerve roots. The brain appeared normal or showed petechial hemorrhages at various points on the surface. Upon these observations they developed a theory that concussion shock is due to vibrations set up in the atmosphere which, transmitted to the organism, act injuriously by violently agitating the unprotected tissues.

Hooker (1923) determined the physiological effect of air concussion. Experimental observations were made upon dogs, cats, rabbits, and frogs exposed at various distances to small charges of explosive and to gun-blast. According to this investigator, bruising with rupture of the lungs was the single gross lesion found postmortem, and this lesion was probably the primary cause of death when it occurred.



Barcroft (1940) also investigated the physiological effects of blast and established four points from his experiments (1) that only animals placed in the open and within 15 feet from the exploding bomb suffered ill effects (2) that the Anderson shelter gave immunity at 15 feet and outward to blast injuries (3) that the animals situated further than 15 feet suffered no demonstrable lesion of their organs and (4) that the lesions found in the animals nearest to the explosion were essentially in the lungs. Histologically these lesions consisted of bruising of the



Fig. 1. Moderately severe hemorrhages in the lungs of a rabbit exposed to blast. (After Zuckerman)

lung surface along the line of the ribs and vertebral borders and extended for one quarter to one half inch into the lung tissue. Other small hemorrhages were found deeper especially around the small bronchi. From a study of animals observed over a subsequent period of weeks the exposure to blast appeared to have had no permanent effect.

Until recently the manner in which the pulmonary lesions are caused by the blast had not been studied. Various workers have however speculated about this on the basis of the character of the lesions and three possibilities have been suggested. The first is that the lesions are due to the lowering of alveolar pressure by the suction wave acting through the respiratory passage with the consequent rupture of the



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alveolar capillaries. The second is that the lesions are caused by the distention of the lungs with air. The third is that the lung lesions are due to the impact of the pressure wave on the chest wall.

Zuckerman (1940) in a recent, more elaborate investigation designed to determine the mechanism by which the lung lesions were produced, confirmed the extensive injury to the lung tissue in a wide variety of animal species. The view which his experiments substantiated was that the lesions were due to the impact on the thoracic wall of the pressure component of the blast wave. Rabbits were exposed to the explosion of hydrogen and oxygen in balloons. When very close to the balloon, the lesions were found mainly or entirely localized on the side facing the balloon. It appeared to be a direct impact effect, and not some more general pressure effect through the trachea. In the latter instance the lesion would be expected to be bilateral. In another set of experiments one-half of the animal was covered with sponge rubber; if the covered side were placed toward the explosion the animal sustained practically no lesions, but if the covered side were away from the explosion it received many lesions on the uncovered side facing the explosion.

Near the explosion of a 70 pound charge (at 13 to 18 foot distance) the animals would be found dead within one minute. At these distances the positive component of the blast wave (hydrostatic pressure) varied between 126 and 63 pounds per square inch. Further away, in a zone of lower pressure (at 18 to 20 feet) the animals would die, as a rule within 24 hours. The clinical features were fairly constant, including air hunger and dyspnea. Still further away was a zone (at 20 to 50 feet) in which the animals survived and recovered, and in which they showed no external appearance of injury, though postmortem examination revealed characteristic visceral changes.

In none of the animals which died was there any external sign of injury, and in no case were fractures observed. The predominant lesion was bilateral traumatic hemorrhage in both lungs varying in degree according to the distance of the animals from the explosion (Fig. 5).

Microscopically, the lesser degrees of damage appear as a small zone in which the alveoli and the smallest bronchioles are filled with blood. The alveolar walls are often disrupted, the hemorrhage originating in the torn alveolar capillaries. In severe grades of damage, large areas of the lung are disrupted and hemorrhagic and the larger bronchi become filled with blood (Fig. 6).

No changes were observed in the other organs and tissues of the body. Zuckerman concluded by emphasizing that in the case of fatal injuries due to blast, "what actually caused death in such cases—in fact, what



caused death in experimental animals subjected to blast alone was not known, and it was to the solution of that problem that some experiments at the present were being directed

Stewart et al (1941) more recently report their experimental investigation of blast injury to the central nervous system. Again, they emphasize that lesions of the central nervous system may be produced. They state that though pulmonary damage is apparently a constant finding and at times is very extensive, it seems unlikely that it is responsible for either sudden death or later fatalities except in a contributory way. They suggest that the mechanism responsible for the cerebral lesion was the hydraulic like pressure on the central nervous system, in its firm encasement, resulting from sudden compression of the thoracic cage with consequent violent back pressure on the venous side.

### Treatment of the Injured

*Prevention* On the basis of both the clinical and experimental observations it may be stated that prophylaxis is possible. And there are two measures of direct importance in the prevention of this form of trauma.

First is the application of the general principle of protection from the blast wave by the use of air raid shelters and the like such as ditches, holes, and gutters on the ground. As an emergency measure one should lie flat on the ground in the prone position, since the back yields less to injury than the front part of the chest.

Second is the application of some direct measure of protection by covering the chest with sponge rubber or some similar material.

*Management after the injury* The importance of early recognition of the lung injury in order to treat it rationally, cannot be overemphasized. If, for example, as the result of careful clinical observation it is concluded that pulmonary lesions are present in those whose degree of shock is out of proportion to the apparent severity of the injury, then the indication will be to avoid unnecessary operative intervention and open anesthesia and to concentrate on the treatment of the shock.

It is too soon to determine in full the treatment which may be required. *Complete rest* is essential, and in view of the condition of the lungs found at necropsy and the embarrassed breathing clinically, every effort should be made to avoid any additional trauma and work that might be added to the already traumatized lungs. Oxygen therapy would consequently appear to be worthy of more extensive use. Above all, an awareness that such damage to the lungs may occur should stimulate all concerned to be watchful for this hidden type of danger among those injured in air raid casualties.



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### **Summary**

This war differs from those preceding in that aerial bombing has assumed a dominant role in the attack. Consequently, the civilian population is, at least in certain phases of the struggle, more vulnerable to attack than the military personnel. This new technique of warfare has created other problems of injury and particularly to the lungs; however, lung injury in the intact thorax occurs more frequently during peacetime than has been formerly recognized and reported.



FIG. 6. Photomicrograph of the lungs of a rabbit exposed to blast, showing many alveoli filled with blood cells and the disrupted alveolar walls. (After Zuckerman.)

The pertinent physiological and morbid anatomy of the thorax is reviewed. A case of lung injury unrecognized clinically and discovered at postmortem, similar to that of the lung injury from blast is presented. A brief review of the power of high explosive, and of the nature and physics of the explosion is presented. The outstanding clinical findings of blast injury to the lungs are as follows:

*Symptoms* may vary from a slight degree of respiratory distress to a complete cessation of respiration depending on the degree of injury inflicted by the blast wave. In general, varying degrees of shock are present accompanied by dyspnea. Cough and hemoptysis also are frequent. Symptoms referable to abdominal and cerebrospinal nervous disturbances have been reported.



*Physical examination* reveals, in general, no gross injury particularly pointing to the thorax. However, one clinical aspect of importance dealing with this type of injury that demands constant attention is that the gross lesions found elsewhere in the body must not be allowed to overshadow the possible lung injury which is now known to be probable without evidence of external injury to the chest. The importance of this special precaution, clinically, cannot be overemphasized. The presence of blood in the nose or mouth and bloody sputum, and the characteristic x-ray appearance of the chest are of considerable diagnostic importance.

The *postmortem findings* always reveal extensive hemorrhagic lesions in the lungs. All cases show general pulmonary congestion. Pleural hemorrhages are present only as an extension from deeper areas.

The results of the experimental studies carried out by various investigators have confirmed the clinical and *postmortem* findings that pulmonary lesions predominate. The view substantiated by the recent experiments is that the lesions are due to the impact on the thoracic wall of the pressure component of the blast wave. More recent studies have again called attention to the evidence that lesions of the central nervous system may be produced by blast. It has been suggested that the mechanism which is responsible for the cerebral lesion was the hydraulic like pressure developed from sudden compression of the thoracic cage with consequent violent back pressure on the venous side.

Prevention of this form of injury is better than treatment. Both the general and direct measures for prevention have been discussed. The principles of treatment have been discussed in the light of the available clinical and experimental observations and attention is called to the necessity of keeping in mind this type of lung injury regardless of whether injuries are found elsewhere in the body.

### Conclusions

- 1 Lung injury without external evidence of trauma occurs more frequently in peacetime than has been recognized and reported.
- 2 In a bomb explosion the pressure wave of the blast may produce pulmonary lesions without resultant evidence of injury to the thoracic cage. The lesions are principally due to the impact on the body wall of the pressure component of the blast wave. That this form of trauma produces lesions predominantly in the lung is now abundantly confirmed.
- 3 It appears that the mechanism responsible for the cerebral lesion is the hydraulic pressure on the central nervous system, in its firm encase



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ment, resulting from sudden compression of the thoracic cage with consequent violent back pressure on the venous side, and that this mechanism may prove to be the explanation for the cause of sudden death in certain cases reported.

4. Prevention is better than treatment; the necessity of providing adequate general and direct protection, particularly to those who are prone to exposure to the bombing attack is evident.

5. After injury complete rest is essential. Every effort should be made to avoid any additional trauma and add extra work to the already damaged lungs. Oxygen therapy should be used more extensively.

6. The knowledge that such damage to the lungs may occur should stimulate all to be watchful for this type of injury especially among air raid casualties.

7. This review by no means concludes the problem of lung injury due to the detonation of high explosives. It is hoped that present and future investigations will bring greater and more accurate knowledge.

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*Summary of Non flying Accidents (Non Pilots)* — Compression fractures 13 (fit for duty 4 light duty 5 sick leave 2 invalided 1 untraced 1) Fractures of transverse processes 16 (fit for duty 15 invalided 1) Other injuries 10 (fit for duty 8 invalided 2)

Of the patients who were ultimately invalided from the Service one with a compression fracture of L 1 subsequently developed nephritis for which he was invalided. Another fell heavily on the back of his head and neck as the result of a motor accident fracturing the transverse processes of C 7 and D 1 with irreparable injury to the brachial plexus. He subsequently had to undergo amputation of the flail limb and was



FIG 1 — B lateral view of dislocation of articular processes of fourth and fifth cervical vertebrae. Radiograph taken on a film.

invalided from the Service. A third had a dislocated C 5 as the result of a motor accident with complete paralysis of the lower limbs. The dislocation was reduced by a pull of 60 lb on the head two days after the injury but there was no evidence of recovery six months later and he was invalided. The fourth fractured the lamina of C 3 as the result of vaulting. He was placed in a plaster in full extension but six weeks afterwards he had an epileptic form convulsion when radiological examination revealed a forward subluxation of the vertebrae. The plaster was renewed but he later became excited and after a period of mental



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observation was invalidated from the Service nine months from the time of his accident. It is doubtful how much of his symptomatology was due to the mechanical injury of the vertebrae, as no paralysis was noted

### Method of Treatment

It is possible only to generalize on the subject of treatment, as these cases have arisen throughout the Service and have been treated in various stages by our colleagues, while some received their initial treatment at the different civilian hospitals to which they were admitted following their accidents. We have attended some of these cases, and one of us



FIG. 2.—Same case after unsuccessful attempts at reduction. Displacement persists.

(P. A. H.) has had the opportunity of examining most of them and of taking charge of many. Full primary radiological investigation of all cases with the least suspicion of spinal injury after an accident is essential, as vertebral injuries are at times discovered only by following this practice.

As a general rule the teachings of Watson Jones and Bohler have been applied in principle—that is, early reduction by hyperextension and fixation in plaster-of-Paris. We ourselves practise early ambulation when possible, and it would appear that our colleagues in the Air Force have a similar outlook. Open operative procedure has not been recorded



except in the one case of cervical dislocation quoted above when delayed spinal fusion was successful. Laminectomy has not been performed in the series examined. One case of bilateral dislocation of a cervical vertebra which proved most resistant to reduction deserves a detailed description.

### Reduction in a Case of Bilateral Cervical Dislocation

A sergeant instructor in physical training, aged 32, was demonstrating a somersault when he slipped and fell on the back of his head. He was found to have sustained a bilateral dislocation of the articular processes between C. 4 and 5 (Fig. 1). He had an immediate partial motor



FIG. 3.—The case after reduction

paralysis of the upper and lower limbs which was followed within two days by complete motor and sensory paralysis below the level of C. 5. Traction was attempted followed by a weight extension of 16 lb. for six days. This failed to effect reduction or clinical improvement (Fig. 2). With general anaesthesia (gas and oxygen) mechanical traction was applied by means of a double loop of wool skein placed under the chin and occiput connected to a system of pulleys with the incorporation of a dynamometer. Countertraction was obtained by the shoulder pieces on the operating table and straps passed around the body both the table and the pulleys being attached to fixed points in the structure of the



operating theatre. During the application of stress observation was continued by means of a Victor portable x-ray set combined with the use of a daylight fluoroscope by an assistant.

Full distraction was not obtained until the dynamometer, which was accurate, registered a pull of 160 lb., when the articular facets separated. The antero-posterior displacement was then corrected by a strong forward pull applied through a loop of unyielding calico bandage passed behind the lowest part of the neck, together with a forcible backward thrust applied to the transverse processes of the vertebrae above the injury. As soon as the displacement appeared to be corrected, as judged by the



FIG. 4.—Radiograph taken eighteen months after reduction.

fluoroscope, the traction was released and the vertebrae adopted a correct position (Fig. 3). Plaster-of-Paris was applied immediately in order to maintain hyperextension. Later lumbar puncture was performed, and Queckenstedt's test gave a satisfactory response to compression of the jugular veins and to respiration.

The subsequent history showed recovery of minute movements of the toes in three months, followed very slowly by a steady return of power and sensation until, eighteen months after his accident, full function was restored. He returned to duty, and two years later he continues to be fit.



The latest radiograph, taken six months ago, shows only slight anterior displacement with a little absorption of the lip of the body of the lower vertebra (Fig. 4)

### Commentary

Current literature reveals wide acceptance of the principles of treatment of crush fracture of the body of a vertebra by early reduction by means of hyperextension and adequate fixation. Usually this reduction is effected by the technique of either Watson Jones or Davis (Watson Jones, 1931, Davis 1929). Williamson (1938) considers that concomitant fracture of a neighbouring articular process may render these methods dangerous, and he prefers a slower reduction on a hyperextension frame in these cases. Watson Jones (1931) does not appear to consider that this danger exists. On the other hand, damage may be done to the cord by attempting hyperextension of the spine when a dislocation and displacement of the articular processes accompanies a fracture of the body. Here a displaced and locked articular process may act as fulcrum for gross hyperextension and undue traction upon the cord. In these cases reduction of the dislocation, usually by open operation, must precede hyperextension. Excision of the articular process may be necessary (Watson Jones, 1938, Rogers, 1938).

The complication of paralysis is no contraindication to hyperextension, but is rather a strong indication for early reduction. It is held that much of the initial paralysis is due to spinal concussion and is therefore transient, although recovery may be delayed. Pressure on the cord caused by malposition of the vertebrae may result in permanent damage, local anaemia. At first it is almost impossible to differentiate between such a paralysis and that due to mechanical crushing of the cord, which is irreparable. Hauser (1935) reports three cases of spastic paralysis which were improved by hyperextension even after the lapse of time. One case was four months, another three years, and the third six years after the injury had been received. In the latter two cases a fusion operation was performed after the improvement which followed reduction.

Effective immobilization in a plaster jacket is usual. The patient must become accustomed to the jacket rather than have its function destroyed by ill advised, albeit sympathetic removal of little bits here and there until the essential extent of the plaster is lost. Early ambulation, subject to the perfect efficiency of the plaster, is an excellent practice where possible. Not only is the tone of the spinal musculature improved but the patient does not develop the rapidly acquired im-



pression that he is and will remain a cripple. The plaster must be retained until consolidation is complete—three months for slight cases in six months or more for the more severe.

Laminectomy has practically disappeared from the treatment of these cases, although some authors describe various and at times complicated indications for its performance. The impression given by present literature is that it is seldom necessary, and "it is not likely that any improvement in the patient's condition will result" (Wakeley, 1936).

The mechanism of these injuries has been adequately explained in, for example, a paper by Lambrinudi (1936). We find it difficult to agree that fractures of transverse processes are essentially traction fractures. While we agree that these may occur possibly, as Koudienko (1936) suggests, by sudden muscular action in a fully rotated spine, we find that of sixteen cases of this injury in the series examined in this paper eleven gave a history of a definite blow over the affected site. The other five had indefinite histories which might have indicated either direct or indirect trauma.

Methods of reduction of dislocations of the cervical vertebrae are a trifle diverse. Skeletal traction is advocated by Crutchfield (1936), Hoen (1936), and Barton (1938). The advantages and disadvantages in the application of skeletal traction to the skull are fairly obvious. Jefferson (1933) advocated postural traction, with fixation of the head in extension by means of a sling under the chin. We would refer to the method of controlled and observed powerful traction practised by one of us (P. A. H.) and described earlier in this paper, with the comment that such a method gives the operator an assurance which he would not otherwise enjoy when dealing with such a vital area.

### Summary

Fifty-seven cases of injury to the vertebral column have been reviewed, of which nine were the result of flying accidents and sixteen affected flying personnel.

The majority of the flying personnel affected returned to full flying duties.

A method of controlled traction under visual observation is described for the reduction of a cervical dislocation.

A few comments are made upon current literature.

We wish to acknowledge and stress the fact, to which we have previously referred, that many of our colleagues have treated a proportion of these cases, while others have been transferred from civil hospitals. References to the current literature have been provided and



papers for study lent by the librarian of the Royal Society of Medicine, to whom we would express our gratitude

\* In the tables and case summaries the following abbreviations have been observed A1—Fit for full flying duties A2—Fit for limited flying duties A3—Fit as combatant passenger in aircraft A4—Fit as non-combatant passengers in a craft B—Fit for ground duties t—Temporarily unfit p—permanently unfit h—Fit for duties at home only

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# INVESTIGATIONS CONCERNED WITH PROBLEMS OF HIGH ALTITUDE FLYING AND DEEP DIVING; APPLICATION OF CERTAIN FINDINGS PERTAINING TO PHYSICAL FITNESS TO THE GENERAL MILITARY SERVICE

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During periods of emergency the prime function of the military surgeon lies in the field of preventive medicine. Without minimizing the importance of the brilliant achievements in therapeutic medicine as exemplified by the surgical contributions of service physicians entering from civil life, it can be said that the preventive aspects of medicine as applied to large groups of men training for combat, are of greater importance in the successful waging of warfare.

For military success depends not so much upon the proper restoration of the injured to health as it does upon the maintenance of a continual state of well being in personnel subjected to adverse environments.

The accomplishment of the objectives of preventive medicine as applied to the elimination of disease and the maintenance of high standards of physical fitness requires organization and technique usually developed only through long and observant experience in military life. In the acquisition of this experience test and research endeavor play an important role.

In that phase of preventive medicine aimed at the prevention of disease, far reaching immunologic studies have in their application to military life eliminated or minimized the occurrence of small pox, typhoid fever, tetanus, cholera, yellow fever, and even streptococcic and gas bacillus infection.

Disease, which eliminates men from combat, however, is but one of the many noxious factors affecting fighting personnel. Of the same order of importance are the more insidious agents of fatigue and injury undermining the full capacity for duty and arising from such factors as extremes of heat and cold, oxygen deficiency at high altitudes, great variations in barometric pressure incident to deep diving and high altitude flight, noise and vibration, loss of sleep, excessive muscular exertion, and the stress imposed by arduous duty.

These aspects of preventive medicine are the more recent concern of investigative endeavor on the part of the military surgeon. In this discussion are presented the results of some studies pertaining to high altitude flying and deep sea diving illustrative of medical research directed toward



## *Investigations Concerned with Problems of High Flying and Deep Diving*

the maintenance of the individual in the highest state of mental and physical health.

From the military point of view, the objectives of deep sea diving and high altitude flying are divergent. Deep sea diving is usually concerned with submarine rescue efforts and the salvage of disabled and sunken craft, while high altitude flying serves as a means of destruction.

From the physiologic point of view, however, high altitude flying and deep sea diving have a great deal in common. Both fields demand stringent physical and mental qualifications for personnel and the maintenance of high standards of physical fitness.

In both fields individuals are removed from a normal environment and subjected to rapid and great changes in pressure. Under these extremes of pressure pure oxygen or mixtures of helium and oxygen are required, artificial heat must be applied, factors producing fatigue minimized, and a high state of morale maintained. Efficient existence in both fields depends upon the effective control of the adverse external forces in the effort to keep constant the internal environment of the body.

During the last World War flying was usually conducted at altitudes of 15,000 feet or less, or in an environment in which the aviator could obtain his oxygen supply from the ambient air.

At the present time flying at altitudes between 15,000 and 30,000 feet has made necessary the inhalation of pure oxygen. As the war progresses aerial fighting and bombing operations may in view of the growing efficiency of land and other defences, be expected to take place at even higher altitudes in the range of 30,000 to 45,000 feet.

A prime factor relative to supremacy in aerial fighting is the ability of men and machines to function at high altitudes. The medical officer must therefore consider those problems arising when aviators are projected from a normal environment into the stratosphere, essentially a change involving large fluctuations in barometric pressure.

It is here that the experience derived from systematic studies in relation to deep sea diving and submarines can be applied in the solution of problems incident to existence in the upper layers of the troposphere. Not only does this experience apply to specific problems but special procedures developed for the selection of personnel and the maintenance of physical fitness of men crowded in the adverse environment of the submarine are applicable not only in aviation but also to the military service as a whole.



Symptoms Arising from a Rapid Change in Barometric Pressure,  
Involved in Ascent to High Altitudes

In the study of this problem essential conditions with respect to pressure alterations can be simulated in the laboratory by means of a steel chamber

The first consideration relates to the effect on the individual of rapid variations in barometric pressure. It is in this connection that the important distinction must be made between the instantaneous effect of the compression or rarefaction force itself, in contrast with reactions brought about by disturbances in gaseous equilibria incident to the fluctuations of pressure

An aviator, for example, approaching altitudes of 31,000 feet equivalent to a pressure of 0.25 atmosphere is subject to the same force or rapid decompression as affects the deep sea diver in an ascent from a depth of 100 feet equivalent to 4 atmospheres pressure to the surface

Yet it is a remarkable phenomenon that pressure can be decreased from 14.7 pounds per square inch at sea level to 3 pounds per square inch at 40,000 feet without an apparent effect on protoplasm. Moreover, the compression of the tissues of the body from barometric pressures of 3 pounds per square inch to pressures as high as 215 pounds per square inch is in itself without demonstrable physiologic effect

By contrast, gases dissolved in tissues and present in nasal, aural, and intestinal spaces are involved in new equilibrium adjustments relative to the altered pressure. It is these gaseous disturbances that may give rise to symptoms

*Decompression Effects* As the ambient air pressure is lowered during altitude ascent, air usually finds free egress from the paranasal sinuses and from the spaces in the middle ear and mastoid bone. Occasionally the presence of mucous secretion from infected lining membranes blocks the outward passage of air so that the pressure in the occluded spaces is increased relative to the pressure in the enveloping membraneous tissue. This difference in pressure elicits pain. As a rule, however, the aviator and the diver experience difficulty only during compression as in descent from altitudes or into the depths of the ocean respectively

A related phenomenon accompanying diminution in pressure is the expansion of gas in the stomach and intestines. If the gas is sufficient in amount, the abdominal pain and distension may be the limiting factor in altitude ascent. The abdominal gas is usually residual nitrogen of swallowed air and is readily controlled by the elimination of gum chewing and other practices inducing salivation and swallowing



**Compression Effects:** *Aero-otitis media* occurs almost without exception during descent from high altitudes when the barometric pressure is increasing. An essential fact with reference to traumatic otitis media and injury to sinusal membranes is that obstruction due usually to infection of the upper part of the respiratory tract creates a difference in pressure between tissue membranes and the adjacent spaces. In contrast to the effect of a decrease in ambient pressure, compression tends to elevate the tissue pressure above that existing in the aural and sinusal spaces and to bring about congestion, edema, and hemorrhage. We have found that hearing may be impaired temporarily but complete recovery of auditory function is to be expected as revealed by repeated audiometer tests on divers. Persistent infection of the injured aural and sinusal tissues rarely complicates recovery except in swimmers.

Another cause of traumatic otitis media observed in our tests is indirectly brought about by oxygen inhalation. During descent from high altitudes if oxygen is inhaled, voluntary opening of the auditory tubes in the effort to equalize pressure results in the introduction of oxygen in the spaces of the middle ear and mastoid cells. During the next 24 hours oxygen is absorbed from these spaces and is replaced by nitrogen provided that the auditory tubes are voluntarily opened from time to time. During sleep, however, suspension of voluntary effort to swallow results in a cupping action on the middle ear tissues as the oxygen is absorbed.

Prevention of this type of injury can be effected during descent to the ground level if air is breathed at or below the 15,000 foot level.

The conclusion is reached therefore that apart from injury to aural and sinusal tissues, compression of the body is without physiologic effect.

These disturbances, however, may be considered as minor compared with the serious complications that arise from the liberation of gas bubbles in the blood stream.

### **The Problem of Aeroembolism**

If an adequate oxygen supply is maintained through the inhalation of pure oxygen then bubble formation in the blood stream giving rise to a condition termed *aeroembolism* constitutes the gravest danger incident to simulated ascents above 30,000 feet.

Fragmentary knowledge and conflicting reports, however, are current with reference to the existence of *aeroembolism*. It seemed worthwhile therefore, to apply to the problem the experience gained in the study of the protean manifestations of compressed air illness. To this end a group of deep sea divers served as subjects for rapid simulated ascents to high



altitudes The divers as a result of too rapid decompression from high pressure atmospheres in previous years had on numerous occasions developed bends From their experiences we have been able to piece together fragments of knowledge into a mosaic that has afforded us a rather clear and comprehensive picture

*Definition of Terms* Three clinical entities arising from bubble formation in the blood stream were anticipated on the basis of diving experience

*Bends*, the most common entity is a term established by usage and refers to pains in the extremities usually in the area of the joints With reference to high or low pressures it will be convenient to refer to divers bends or to altitude bends respectively.

*Asphyxia or chokes*, is another manifestation of intravascular bubble formation probably present as widespread embolism of the pulmonary vessels

*Paralysis*, the third and most serious complication of compressed air illness, is brought about by embolism of the central nervous system chiefly affecting the spinal cord Asphyxia and paralysis, in comparison with bends, are less common manifestations of compressed air illness

*Nature of the Problem* If the symptoms elicited by rapid exposure of individuals to high altitudes are due to aeroembolism, the problem resolves itself into the removal of gaseous nitrogen dissolved in the tissues of the body In this connection we are dealing with the following gas pressures in the capillary and venous blood contributing to bubble formation

Nitrogen	...	...	...	...	573 mm
Carbon Dioxide	.	..	...	...	17 mm
Water vapor	.	.....	....	.	47 mm
Oxygen	.	....	...	.	40 mm (Variable)
					<hr/>
					707 mm



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nitrogen elimination curve, figure 1, therefore serves as a guide not only for the decompression of divers but also for the nitrogen decompression of aviators preparatory to high altitude flight.

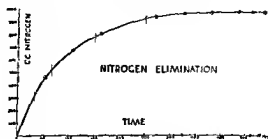


FIG. 1

*Method of Procedure:* Test runs were of two types, short exposures of one hour and long exposures usually lasting six hours.

The subjects for the short exposures were both divers and aviators. The subjects for the long exposures were principally deep sea divers, average age 33, range 29 to 42 years; average height 71 inches; and average weight 184 pounds, range 149 to 205 pounds.

In all tests the rate of simulated ascent and descent was maintained constant at 5,000 feet per minute.

In a typical experiment the subject assumed the sitting position at rest and breathed 99 per cent oxygen from the time that the ascent was started until the termination of the run. Prior to ascent a period of 3 minutes was allowed for washing out the residual nitrogen in the lungs. The subject was then locked in and placed "on his own" until the termination of the run either at the end of 6 hours or earlier if symptoms supervened. Glass ports allowed a close watch to be maintained on the subject.

*At the ceiling altitude a series of recordings were made by the subject in order to ascertain his state of well being and his ability to carry out assigned tasks.*

The temperature in the chamber was fairly constant at 79° F. dry bulb, and 72° F. wet bulb.

For oxygen inhalation the usual system employed consisted of a rubber helmet, bag reservoir, canister containing a carbon dioxide absorbent, and a motor blower to provide gas circulation. These parts formed a closed circuit which was rinsed at 30-minute intervals to ensure a 99 per cent oxygen concentration.



# War Medicine

## Experimental Results

### Long Exposures

The essential data are recorded in the decompression chart, figure 2, which serves as the basis for the following presentation

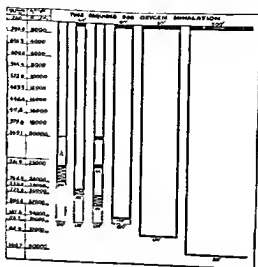


FIG 2 Decompression chart for the prevention of aeroembolism

*Altitudes Attainable Without Previous Oxygen Inhalation and Favorable to Prolonged Stay.* Rapid ascents up to a level of about 20,000 feet are not attended by ill effects during a period of 4 hours. Following this 4 hour period the altitude may be increased to 35,000 feet without the incidence of symptoms arising during a 2 hour period of exposure. Rapid ascents to levels between 20,000 and 25,000 feet, however, have led us to designate this altitude range indicated by the dotted area on the chart, as one of 'silent' bubble formation, although elevation subsequently to an altitude of 35,000 feet followed by an exposure of 2 hours, did not elicit pain.

The assumption that bubbles are present is supported by the occasional debilitating fatigue developing after return to the ground level and also by the fact that oxygen inhalation in this range of altitude is less effective in preventing symptoms than is oxygen inhalation at or below 20,000 feet, when the altitude is subsequently increased to 35,000 feet.

Ascents can be made to altitude levels between 25,000 and 28,000 feet where men may remain for a period of 4 hours to reach ultimately an altitude of 35,000 feet for a stay of 2 hours.

Mild bends, indicated by the heavy lines running cross wise, may



*Investigations Concerned with Problems of High Flying and Deep Diving* appear either between 25,000 and 28,000 feet during the stay of four hours or subsequently when the altitude is increased to 35,000 feet. The symptoms, however, are usually not of sufficient severity to terminate the test run.

*Oxygen Inhalation for a Period of Forty-five Minutes at Ground Level Followed by Rapid Ascent. Figure 2, Column 2:* The breathing of oxygen for a period of 45 minutes at the ground level enables individuals to reach altitudes of 29,000 feet to 30,000 feet for a stay of 4 hours, the altitude subsequently can be increased to 35,000 feet for a stay of 2 hours.

*Oxygen Inhalation for a Period of Ninety Minutes at Ground Level Followed by Rapid Ascent. Figure 2, Column 4:* Oxygen inhalation at the ground level for a period of 90 minutes permits an ascent to an altitude of 34,000 feet for a stay of 4 hours followed by an ascent to 35,000 feet for a duration of 2 hours.

*Oxygen Inhalation for a Period of One Hundred Eighty Minutes at Ground Level Followed by Rapid Ascent, Figure 2, Column 5,* will prevent bends during a period of 2 hours at 37,000 feet. Bends, however, may occur during the third or fourth hour of exposure.

*Oxygen Inhalation for a Period of Three Hundred Minutes at Ground Level,* permits an ascent to an altitude of 37,000 feet for a stay of at least 6 hours. Upon the return to ground level men remain in good physical condition.

Column 6, Figure 2, has not been completed at this time but it is anticipated that a period of 300 minutes for decompression is ample for an exposure of 2 hours at 40,000 feet. In this study it did not appear desirable to complicate the picture by symptoms attributable to the low oxygen pressure existing at 40,000 feet and equivalent to the oxygen pressure at 12,000 feet when air is inhaled.

*The Value of Oxygen Inhalation for the Purpose of Nitrogen Removal at Altitudes Above Sea Level:* If equal protection against the development of aeroembolism could be afforded by oxygen inhalation at higher altitudes, then the feasibility of oxygen inhalation for this purpose is enhanced.

So important is this consideration that the following data are given. For a constant rate of ascent at 5,000 feet per minute, oxygen inhalation for a period of 300 minutes *at sea level* rendered safe an ascent to 37,000 feet for a period of 4 hours. Likewise oxygen inhalation extending over 300 minutes *at 20,000 feet* rendered safe an ascent to 37,000 feet for a stay of 4 hours.

The tests indicate that up to an altitude of about 20,000 feet oxygen inhalation is probably as effective in promoting nitrogen removal as is



oxygen breathing at the ground level. In other words, ascent can be made from the ground level at a rate of 5,000 feet per minute to any altitude short of 20,000 feet in order to effect nitrogen elimination.

The altitude of 20,000 feet appears to be a critical level with respect to manifest bubble formation. It must be remembered, however, that variation of several thousand feet above or below 20,000 feet may be expected, depending primarily on age and physical condition of the men exposed.

At an altitude of 25,000 feet in contrast with 20,000 feet, decompression in the sense that the tissues were rendered nitrogen free, was not as effective as at sea level for corresponding time periods. With reference to chart, figure 2, the third column gives values for a decompression period of 45 minutes at 20,000 feet and 45 minutes at 25,000 feet total time 90 minutes. The altitude reached however, was but slightly higher than the ultimate altitude attained following the single 45 minute period of decompression at normal barometric pressure. The effectiveness of the two 45 minute periods spent at 20,000 and 25,000 feet respectively stands in contrast with the results obtained when oxygen was inhaled for a period of 90 minutes at normal barometric pressure.

From these considerations and the fact that no symptoms with the exception of late fatigue have been recorded during or following ascents to altitudes between 20,000 and 25,000 feet, it seems appropriate to designate this altitude range as an area of silent bubble formation, made manifest only by a sudden increase in altitude or by the late onset of fatigue after return to the ground level.

*Value of Helium.* The prolonged period of oxygen inhalation required to ensure adequate nitrogen removal for safe ascents above 34,000 feet renders this procedure impractical for interceptor pilots.

If pilots could exist in an oxygen atmosphere prior to flight the problem might be solved. However, the toxic effects of pure oxygen and the fire hazard preclude its use under these conditions.

A helium oxygen atmosphere on the other hand overcomes these difficulties and as our laboratory tests have shown, body nitrogen will be removed as effectively as though pure oxygen were breathed. Since helium is only one third as soluble in fat compared with nitrogen the quantity of gas available for bubble formation especially in bone marrow which may be 90 per cent fat, is greatly reduced.

In other words the preliminary period of oxygen inhalation to prevent aeroembolism should be greatly reduced when the body is saturated with helium, compared with a similar procedure when the body is in equilibrium with atmospheric nitrogen.



## *Investigations Concerned with Problems of High Flying and Deep Diving*

This inference proved to be true. A period of only 90-minutes of oxygen inhalation was required to eliminate the helium dissolved in tissues in contrast with the 5-hour period required for nitrogen elimination preparatory to prolonged stay of 6 hours at an altitude of 37,000 feet.

The practical application of this fact applies to conditioning rooms in which men can carry on normal activity in a helium-oxygen atmosphere and yet be ready for prolonged high altitude flight with but little preliminary oxygen inhalation.

*Summary of Experimental Results Making Possible Long Exposures at High Altitudes.* These tests have shown that men can ascend to simulated altitudes of 37,000 feet at the speed of a mile a minute. Existence in this rarefied atmosphere will be normal for at least 6 hours, provided that gaseous nitrogen is removed from the body at the ground level or at altitudes up to 20,000 feet.

If sufficient nitrogen is not removed from the body prior to ascent, bends which may be incapacitating develop. Further, asphyxia due to extensive nitrogen bubble accumulation in the pulmonary vessels has in several simulated altitude ascents forced immediate descent.

### **Experimental Results**

#### *Short Exposures*

Under conditions of military flying pertaining especially to interceptor pilots, it may not be feasible to administer oxygen or helium-oxygen mixtures for the purpose of eliminating tissue nitrogen, prior to ascent.

The immediate question arises as to what altitudes are attainable when the period of exposure lasts for one hour. To answer this question a series of simulated flights were made utilizing the same experimental procedure employed in the long exposures except that oxygen inhalation prior to ascent was eliminated.

The results of 60 tests indicated that 28 divers and aviators were able to remain at altitudes of 34,000 feet to 40,000 feet for a period of one hour without symptoms. On the other hand, 32 divers and aviators developed bends and occasionally asphyxia at these altitudes within the hour period.

On the basis of these tests it was concluded that all fighter pilots should be tested to determine their altitude tolerance for a period of one hour at altitudes between 30,000 and 40,000 feet.



TABLE 1  
Symptoms Elicited by Rapid Changes in Barometric Pressure

Subject	Too Rapid Decompression From High Pressure Atmospheres	Too Rapid Decompression to Low Pressure Atmospheres—Present Test Runs
A	Jan May 1939 Debilitating fatigue experienced daily with onset delayed several hours following rapid decompression from 4 atmospheres pressure	Oct 18, 1940 Debilitating fatigue 3 hrs after return to ground level following an exposure at 23,000 feet for 6 hrs
B	Feb 13, 1933 Under 4 atmospheres pressure for 4 hrs 3 hrs after exposure severe substernal irritation, pains in extremities, fever, sweating, malaise, developed March 20, 1933 Exposed to 4 at mospheres pressure for 110 mins 3 hrs following decompression, substernal irritation pain in right knee and right hip, required recom pression May 15, 1933 4 atmospheres pres ure for 120 mins 1 hr following decompression throbbing pain was present in the deltoid area, right arm accompanied by mild substernal discomfort	Dec 5, 1940 20,000 feet for 45 mins ; 25 000 feet for 45 mins ; 30,000 feet for 90 mins , 37,000 feet for 49 mins ; after 23 mins at 30,000 feet and continuing at 37,000 feet, pain was felt in left shoulder and in both knees Extreme fatigue was present 5 hrs after return to normal pressure Oct 28, 1940 25,000 feet for 240 mins ; 35 000 feet for 120 mins After 2 hrs at 25,000 feet, pain developed in left shoulder At 35,000 feet pain was felt in the right knee accompanied by substernal distress Complete relief after return to sea level
C	1933 Spinal cord injury, pain was present in right knee, residual foot drop and hyperactive reflexes were observed for a period of several weeks followed by complete recovery May 10, 1940 Exposed at a depth of 90 feet for 9 hrs 1 hr following decompression diver developed pain in right knee, relieved by 4 hrs recompression	Oct 31, 1940 27,000 feet for 114 mins Developed pain in right knee, symptoms progressive Pain relieved at 14,000 feet Dec 12, 1940 Exposed at 20,000 feet for 300 mins , at 37,000 feet for 10 mins Pain developed in right knee at 37,000 feet, abated at 25,000 feet
D	May 8, 1940 Exposed at 90 ft. for 9 hrs 65 mins following decom pression, severe pain was experienced in left elbow Recompression required	Nov 11, 1940 Surface oxygen inhalation for 45 mins ; at 31,000 feet for 111 mins After 90 min pain developed in left elbow and radiated to the shoulder Pain subsided at 21,000 feet
E	April 16, 1940 Exposed at 90 feet for 6 hrs 4 hrs following decom pression pain was felt in both knees accompanied by fatigue	Dec 6, 1940 At 20,000 feet for 40 mins , at 30,000 feet for 97 mins Pain developed in the left knee at 37,000 feet Pain subsided at 23,000 feet



**The Symptoms Elicited by Rapid Ascent to High Altitudes Compared with Symptoms Resulting from too Rapid Ascent from Diving Depths**

In 92 test runs bends developed 40 times, extreme fatigue was manifest twice, and signs of pulmonary embolism appeared in three tests.

Bends, therefore, represent the usual clinical entity incident to rapid ascent to simulated high altitudes. The more serious complication of pulmonary embolism giving rise to asphyxia on 3 occasions indicates the grave danger inherent in rapid ascents to high altitudes when nitrogen is not previously removed from the tissues.

The overwhelming nature of asphyxial pulmonary embolism is indicated by the large quantity of gas, measured in hundreds of cc., capable of forming emboli. Fortunately with adequate recompression, that is, during rapid descent from high altitudes, symptoms are ameliorated or disappear.

In answer to the fundamental question as to whether "altitude bends" are similar to "diving bends," Table 1 is presented outlining the symptoms exhibited by men exposed to extremes of high and low barometric pressure.

*Etiology of Bends:* The frequent reference to bends merits a brief discussion as to etiology. Bends as one of the manifestations of too rapid decompression denote a shifting, aching type of pain present in the extremities usually in the region of the joints.

To explain this type of pain it has been frequently assumed that bubbles are present in nerve trunks, tendon sheaths, and joint spaces.

In our studies, however, gas bubbles to which symptoms could be attributed have been observed only in blood vessels and we believe that the etiology of bends is essentially the result of embolic ischemia of osseous tissue.

The bones because of their peculiar blood supply and structure which includes bone marrow with its high absorption coefficient for nitrogen, serve to retain gas bubbles forming in situ or reaching the bones by way of the general circulation.

Bubbles accumulating in the veins and sinusoids of bone marrow are undoubtedly prevented from readily entering the general circulation by reason of rigid character of the vascular walls traversing the hard substance of bones.

Supporting the vascular ischemia origin of bends is the fact that application of pressure promptly relieves symptoms. This response might not be anticipated were the injury due to extravascular bubble formation which would imply cellular destruction.



Recent reports of characteristic lesions in bone appearing in caisson workers support the view that the symptoms giving rise to bends originate from ischemic changes in bone. However, the existence of these lesions must be corroborated by animal experimentation before final conclusions can be drawn.

*Fatigue Incident to Variations in Barometric Pressure* During the past eight years we have recognized a type of fatigue that merits a great deal of study. It is related to exposure in compressed air and invariably follows too rapid release of pressure usually preceded by an interval of several hours of well being.

This type of fatigue because of its relation to exposure in compressed air and appearing as a frequent prodromal or concomitant symptom of pain is regarded as a manifestation of decompression embolism. Adequate decompression with oxygen administration prevents the syndrome.

Fatigue similar in character to that following exposure in compressed air developed also as a result of too rapid ascent to simulated high altitudes. In these tests factors conducive to fatigue as subnormal alveolar oxygen pressure, cold, vibration, noise and the stress of hazardous duty were absent.

The delayed onset of the fatigue and its cumulative effect were puzzling until it was realized that following a return to normal pressure gas elimination into the blood stream from slowly desaturating tissues might augment the size of gas bubbles to bring about a delayed embolic anoxia.

In a series of daily exposures for example to a pressure of 4 atmospheres the first exposure may see the individual entirely well, the second may be accompanied by delayed fatigue while the third might result in frank bends or a chronic condition might develop characterized by drowsiness, irritability, lack of volition, inability to concentrate and a feeling of constant malaise.

The manner in which the presence of bubbles brings about fatigue has not been determined. It is possible that anoxic cellular destruction with liberation of toxic substances and impaired venous return to the right side of the heart are etiologic factors.

*Concluding Remarks with Respect to Aeroembolism* With the exception of paralysis the symptoms elicited in divers and in aviators as a result of rapid diminution of barometric pressure are similar. More over the symptoms exhibited by both groups of men are relieved by the application of pressure.

It has been long established that symptoms arising in divers are caused by gas bubbles largely composed of nitrogen. While we have not demon-



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strated gas emboli in the body at high altitudes, the evidence derived from these tests leaves little doubt that the etiology of aeroembolism is to be found in the formation of gas emboli.

The fact that nitrogen removal from the body brought about by oxygen inhalation will prevent asphyxial collapse and bends that otherwise occur, is evidence of the common etiology of aeroembolism and compressed air illness.

Real danger is therefore inherent in rapid ascent to high altitudes. On the other hand the removal of body nitrogen commensurate with the altitude attained, makes possible ascents to high altitudes with the certainty of physiologic well being.

### **The Problem of Work at High Altitudes**

At an altitude of 34,000 feet, 0.25 atmospheres, the alveolar oxygen pressure when pure oxygen is inhaled, is of the same order as the alveolar oxygen pressure when air is breathed at the ground level, 1 atmosphere pressure.

An important question concerns the individual's ability to perform work at this altitude, since this criterion constitutes the only valid test of well being.

For the purpose of exercise a stationary bicycle was employed. Figure 3 illustrates the response in respiratory activity and oxygen consumption during rest and work on the stationary bicycle.

At a pressure of 1 atmosphere in comparison with a pressure of 0.25 atmosphere, body metabolism as shown by measurements of carbon dioxide output was essentially unaltered when oxygen was inhaled at the two different pressures.

There was no difference moreover in the feeling of well being during and following the work periods at the simulated high altitude.

While exercise tests were not conducted at simulated altitudes above 34,000 feet, the data at rest indicate that the response to work will affect the body in proportion to the degree that the alveolar oxygen pressure is lowered. The data obtained therefore at altitudes up to 12,000 feet during the inhalation of air should indicate the expected response at altitudes between 34,000 and 40,000 feet during the inhalation of oxygen.

A more exact evaluation of existence at 34,000 feet depends upon prolonged exposures in excess of 6 hours for a period of several weeks.

### **Testing and Maintenance of Fitness for High Altitude Flying and Deep Sea Diving**

Tests to determine fitness for aviation and deep sea diving are the



most comprehensive and thorough in the military service. It is not the purpose of the following paragraphs to review these stringent qualifications but rather to stress those tests of particular significance and to point out the important role that the pressure chamber should play in the examination.

**Altitude Tolerance Test for Aeroembolism** For many years the problem of selecting individuals resistant to bends or air embolism was unsolved. Available tests were of no value in classifying a group of divers as to their susceptibility to compressed air illness.

An advance in our method of selection was the adoption of a pressure test in which an individual exposed to 4 atmospheres pressure for a period of 28 minutes was decompressed to a pressure of 1 atmosphere in 2 minutes.

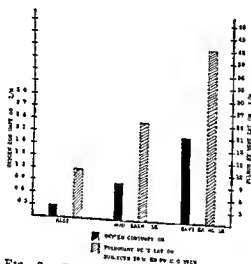


FIG 3 Oxygen consumption and pulmonary ventilation in relation to activity  
 1 Rest—seated on stationary bicycle 2 Moderate exercise—pedaling 20 miles per hour 3 Heavy exercise—pedaling 30 miles per hour

Although men susceptible to compressed air illness were eliminated by this test, it had obvious disadvantages: not only was an undetermined quantity of nitrogen absorbed by the body during the incomplete exposure but also if men developed symptoms as a result of the test procedure, recompression was essential in treatment.

These disadvantages were overcome by decreasing the pressure rapidly from normal in what may be termed an altitude tolerance test. This test embracing the experimental procedure previously described for short ex-



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posures at high altitudes, calls for oxygen inhalation at the ground level followed immediately by a rapid decrease in ambient pressure to simulate ascent at the rate of 5,000 feet per minute.

The simulated altitudes to be reached in the exposure range from 30,000 to 40,000 feet and the duration of the stay at the designated altitude is 1 hour unless aeroembolism develops.

Routine procedure calls for an ascent to an altitude of 30,000 feet and in subsequent exposures at intervals of 48 hours the altitude is increased 2,000 feet provided that the subject remains free from symptoms.

The results of this test procedure have served to classify our deep sea divers as to their resistance to compressed air illness, and our aviators as to their ability to remain free from symptoms at altitudes above 30,000 feet for a duration of 1 hour.

The test procedure is safe when administered under close supervision and the symptoms manifested in the rarefied atmospheres on the basis of current observations can be classified with 3 exceptions as "bends." The 3 exceptions were manifestations of widespread pulmonary embolism giving rise to substernal distress and paroxysmal coughing. These serious symptoms unless followed by rapid recompression would have given rise to asphyxia.

If allowance is made for the residual soreness in the chest experienced by the three men who developed pulmonary embolism, all symptoms were completely relieved when the altitude was lowered several thousand feet.

It is probable that bubble formation will arise in all men rapidly subjected to altitudes above 20,000 feet. It is not known why some individuals are immune and others susceptible to the development of bends. Different species of animals appear to tolerate rapid decompression in accordance with a relationship between surface area and body weight. Mice, guinea pigs, and other small animals, comparatively immune to decompression injury, possess a large surface area in proportion to body weight. Since cardiac output is proportional to surface area, resistance to aeroembolism may be essentially dependent upon the rapidity of nitrogen removal from tissues. Within a given species, *age* and *amount of fat* are important factors governing susceptibility to aeroembolism.

However, of the 60 men examined in the age range of 21 to 43, no certain correlation could be made between the occurrence of aeroembolism and age.

From the point of view of applied physiology the test is of great practical importance. In recent diving operations in the open sea conducted at depths between 375 and 440 feet in connection with the "O-9"



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to diving depths of 150 feet or greater are exposed to the narcotic effect of atmospheric nitrogen. Nitrogen probably by reason of its high fat-water solubility ratio acts as do similar substances in accordance with the Meyer-Overton hypothesis to depress the function of the central nervous system. The resultant altered emotional response and impaired neuromuscular coordination are manifestations of this depression.

An outstanding consideration is that able men by increased effort are able to counteract the impairment and to carry out their assignment although reaction time may be greatly slowed.

The less capable individual on the other hand loses his grasp and objective and exhibits emotional aberrations of the type commonly associated with the ingestion of alcohol.

In effect a *load* has been placed on the nervous system of the individual by the action of nitrogen. The degree and type of extra effort response which enables a man to counteract the stress determines his value for the performance of hazardous types of military duty.

*Tolerance Test for Low Oxygen Pressures at High Altitudes:* With respect to aviators the decreased oxygen pressure in the air at altitudes of 14,000 feet and higher imposes a stress or load on the individual so that responses similar to the effects of alcohol and atmospheric nitrogen at high pressures may be observed.

For each individual there has come to be recognized a ceiling altitude above which rapid deterioration and failure in performance are to be expected. As may be surmised this ceiling shows considerable individual variation because of the interrelation of complex physical and psychologic factors.

During the last war Schneider and Dunlop made extensive tests of the effects of low oxygen pressures and they developed a highly valuable body of physiologic and psychologic data utilizing the Henderson-Pierce rebreather apparatus in their tests for the classification of prospective pilots.

These investigators and others, notably McFarland, found that the progressive decrease in pulmonary oxygen pressure brought about impaired neuromuscular control, a narrowing of the field of attention, a loss of memory, a decrease in the capacity for making choice reactions, and striking alterations in mood.

At present the widespread employment of oxygen in aircraft eliminates the need for a test of anoxia tolerance as a direct criterion of the ability to fly at high altitudes. Nevertheless, the employment of anoxia in a test of endurance and for the evaluation of basic behavior and especially of the ability of an individual to resist drowsiness and main-



tain attention, is too well grounded in extensive investigation to be discarded.

The essential problem now is to work out a uniform procedure involving the performance of simple physiologic and psychologic tasks for evaluating the response of the individual to the stress of anoxia.

It is in this connection that the low pressure chamber affords a more convenient method of maintaining a desired oxygen pressure in relation to time exposure compared with the rebreather test. Current procedures involve exposure of 15 to 30 minutes at simulated altitudes between 14,000 and 20,000 feet.

Under these conditions the distinct factors of physiologic and psychologic response must be correlated with the arterial oxygen pressure and the percentage saturation of the oxyhemoglobin if the variables of physical fitness and psychic reserve are to be evaluated separately.

*Test for Claustrophobia and Nyctophobia:* Any degree of claustrophobia and fear of darkness impairs or may even destroy the efficiency of the deep sea diver or of personnel engaged in submarine duties. Indicative of anxiety neurosis it is therefore a most positive disqualifying mental defect for personnel engaged in hazardous duty. The widespread distribution of these phobias either latent or manifest is not realized until tests are made on individuals enclosed in confined, dark spaces

In the course of experiments designed to measure nitrogen elimination, individuals have worn rubber helmets completely enclosing the head and excluding light. It was found however, that some men became nervous and could not tolerate the presence of the helmet unless light were admitted through goggles

Other men, however, were able to wear the darkened helmet for periods as long as 17 hours. These men have proved to be the most stable individuals when confronted with hazardous tasks in deep diving

For deep sea divers and submarine personnel the test is specific and serves to exaggerate the condition of confinement and deprivation of light characteristic of the environment of these men

For aviators and other service personnel the test permits the detection of a serious manifestation of nervous instability, the anxiety neurosis

During the one hour period of the test good reactors remain apparently normal while individuals with latent tendencies toward claustrophobia are either unable to wear the hood or following the test, exhibit signs of emotional disturbance, usually evident when measurement is made of cardiovascular response.



### Cardiovascular Response

As a part of the procedure to determine physical fitness the estimate of cardiovascular efficiency is of great importance.

In the evaluation of cardiovascular tone the recording of pulse rate before, during, and following exercise, and of blood pressure is a standard procedure. As employed in the Schneider test these observations have long been routine in Army and Navy examinations.

Objections, however, have been raised to the Schneider test in that healthy men under conditions in which they were obviously unfit, made high scores, and that psychic factors in their effect of pulse rate frequently determine the ultimate score.

The value of the Schneider index depends not only upon the care exercised in its recording but also upon the careful control of conditions affecting the individual.

The factor of temperature for example is a real variable in its effect upon pulse rate and blood pressure. We have shown that under carefully controlled conditions the removal of men from a temperate to a tropical climate will cause an increase in pulse rate in response to increased peripheral blood flow, and a fall in systolic blood pressure.

An average Schneider index for a group of 10 men in Long Beach, of 11; may fall to a value of 5 as a result of temperature changes alone.

It should be stressed that the Schneider index must be conducted as carefully as any quantitative laboratory procedure and the results are of value only in proportion to the control maintained over attending conditions.

Because of these limitations the Schneider index may be considered as too refined a test for general service use.

For our purpose a simple test designed primarily to increase exercise effort over the effort required in the Schneider test has been satisfactory. In this test an individual steps up on a box 18 inches high 20 times in 30 seconds. Blood pressure is recorded before exercises. Pulse rate is recorded before, immediately after and 2 minutes after exercise. The pulse beats are counted for a period of 15 seconds and multiplied by 4 for the minute rate.

A second period of exercise follows and the pulse rates are again counted. A third period of exercise or endurance run terminates the test. In the endurance run the subject persists in the step up exercise until the standard rate can no longer be maintained as timed by the metronome.

Tests are usually made in the early morning. Smoking because of its accelerative effect on pulse rate is not permitted from the time of awakening until the completion of the test.



# War Medicine

Good cardiovascular response is indicated by a return in pulse rate to normal after the 2 minute periods of exercise allowing a difference of 4 beats for error. The minimum duration of the endurance run for men in good physical condition is 60 seconds.

Characteristic of men in good condition are low resting pulse rates, diastolic blood pressure values in the range of 70 to 80 mm mercury and systolic blood pressure values not above 140 mm mercury.

TABLE 2  
PULSE RATE

No of men	Age	Wt	Ht	Rest	Immed after exer	2 min after exer	Immed after exer	2 min after exer	Endurance	Blood pressure
<i>Aviators</i>										
5	26	157	71 3	73	115	75	120	78	—	119/74
10	29	162	70 0	77	122	83	129	87	—	117/80
9	34	169	70 5	72	106	72	114	75	—	128/78
10	26	157	69 7	75	114	76	119	83	—	121/76
				78*	118	83	130	88	122	120/75
<i>Deep Sea Divers</i>										
15	34	170	70	79	118	79	125	88	86	120/85
12	30	163	69 1	80	117	93	119	90	79	121/74
16	26	152	70 3	76	109	76	115	78	98	115/76
<i>Submarine Personnel</i>										
10	25	169	70	82	122	88			66 5	
				83	119	81			66 7	
				83	125	87			66 8	124/85
				88†	127	90			66 9	116/77
10				74	114	75			54 8	121/79
				73‡	115	75			54 5	115/75

\* Following 10-day period of pressure chamber tests

† Following a 48 hour period of stationary submergence

‡ Following a 12 hour period of stationary submergence

Should it be desirable to classify the degree of cardiovascular response of healthy men the standard exercise test is repeated successively until the pulse rate fails to return to the resting level at the end of any 2 minute period.

The step-up type of exercise also affords an indication of muscular tonus and neuromuscular co-ordination. Classification of response is designated as excellent, good, fair, or poor.

The test because of its simplicity can be run routinely prior to diving operations or to high altitude flight. It is not unusual during sustained, strenuous activity covering a period of weeks for the diastolic pressure



*Investigations Concerned with Problems of High Flying and Deep Diving* accompanied by loss of vascular tone to rise 20 points or higher above normal. A quantitative estimate as to the nearness of the "break" in physiologic function is afforded by the test.

Values shown in table 2 were obtained when deep sea divers and aviators served as subjects.

*Concluding Remarks:* It is emphasized that an occasional estimate of cardiovascular function is of little value. These tests should be carried out routinely in order that the medical officer may obtain a quantitative evaluation of the individual's cardiovascular response at any given time. In the course of repeated examination each individual acquires a continuous record by which any particular effort response can be evaluated in terms of degree of physical fitness.

### **Application of Findings to the General Military Service**

*Selection of Personnel for Arduous Duty:* Present day mechanized warfare has placed large groups of men in confined spaces, in sealed compartments of warships, in turrets, in armored aircraft, in tanks, and in underground defense systems. These environments present such disintegrating forces acting on the nervous system as noise, vibration, wide variations in temperature, inadequate rest, and confinement. Survival moreover, demands continual alertness and periods of intense activity.

Efficient existence in these deleterious surroundings calls for especially selected men, essentially men possessing the attributes of submarine personnel who do not break down during periods of sustained, intensive operations despite overcrowding, deficient hygienic facilities, vitiated air, and lack of immediate medical care.

In the selection of submarine personnel, objectivity and uniformity of test procedure are maintained in certain phases of the examination by means of the pressure chamber which may be looked upon as representing a contribution of military medicine to the improvement of diagnostic procedure.

As in the selection of candidates for the submarine, diving, and aviation services, the pressure test eliminates men harboring low grade as well as the more apparent chronic infection of the upper part of the respiratory tract, and serves to classify the degree of impairment by the difficulty in making the adjustment to the increased pressure. Men who might otherwise pass a general examination are eliminated by this test for the continual, energetic activity in confined spaces.

Additional tests conducted in the pressure chamber are concerned with mental and emotional response under adverse conditions. For this purpose limited periods of stress not injurious to the individual can be pro-



vided by the anoxia or simulated altitude or by a high pressure atmosphere in which atmospheric nitrogen serves to retard efficient activity

Standardized psychologic tests carried out under these conditions serve to separate those men capable of good effort response from unstable individuals whose capabilities are inhibited by emotional maladjustments

The sealed environment of the pressure chamber can serve as a substitute for the hood test used to elicit manifest or latent claustrophobia and nyctophobia. These phobias as manifestations of the anxiety neurosis specifically eliminate individuals for the arduous duty under discussion. The cardiovascular response can be used as a measurement of the stress placed upon the individual by the abnormal conditions.

*Maintenance of Physical Fitness* It has long been recognized in the submarine service that periods of intense activity must be interspersed with periods of complete rest and recreation in which athletic games participated in by all personnel play an important role.

In aviation appreciation of the importance of pilot fatigue has led for example to preventive measures which have eliminated such practices as altitude flying without oxygen for periods of three hours daily at altitudes between 15 000 and 18 000 feet.

Thus the maintenance of conditioned physical fitness for men engaged in arduous duty is becoming an integral part of preventive medicine carried out by medical officers adept in the application of physiological principles to field practice.

In the attainment of this objective the whole structure and basis of scholastic athletics serves to guide military efforts on the conditioning of men for modern warfare. For athletic competition has demonstrated the value and the kind of training required to enable men to engage in supreme endeavor.

The self sufficiency furthermore characteristic of many of our universities enabling men to live in close association for considerable periods of time can be attained also in the military cantonment.

In this manner the segregation and complete isolation of groups of men will enhance the carrying out of a regime of intensive conditioning and training designed to overcome objectives otherwise unattainable. Group isolation will further serve to combat the incidence of communicable infection of extraneous origin which in the past has exacted a severe toll on military personnel in terms of sick days and weakened man power.

The endeavor of medical officers to teach and train individuals to cope with the adversities of the military environment should in the broader field serve as a nucleus for a national health program.



Although a rehabilitation program aimed at the correction of defects in personnel subject to the Selective Service Act is beginning to take form, the reservoir of civilian population must be imbued with a sustained will to physical fitness that produces health not measured in terms of longevity but in ability to stand up under arduous military duty.

The success of this program will be manifest when the body of able population engages daily in supervised athletic games and exercises and when the automobile is discarded for recreation in favor of the bicycle.



# FATIGUE IN AIRCRAFT PILOTS

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One of the most significant problems in civil and military aviation relates to what is popularly known as pilot fatigue. Conclusions about its nature or even its locus however are almost as numerous as the articles that have been written since each depends largely on the interests or background of the author. Viteles<sup>1</sup> says that the word fatigue used both popularly and scientifically refers to three related phenomena.

An over manifestation in the form of reduced output on the task known as work decrement a physiological state involving changes in organic functions and the production of chemical products of fatigue and a feeling of fatigue or tiredness. Schneider<sup>2</sup> suggests that it is a progressive flagging of efficiency together with subjective sensations of loss of control. Grow<sup>3</sup> has advanced the hypothesis based on wide experience in the field of aviation that fatigue is due to the excessive generation of nerve impulses and originates in the nervous tissue of the body.

The varieties of interpretation may be due in part to the fact that the word fatigue does not have a specific meaning in a scientific sense. It refers generally speaking to a related group of phenomena associated with loss of efficiency. In common usage it is not unlike the word unconscious in psychopathology—a convenient category used to classify certain phenomena that are essentially unknown or not clearly understood yet nonetheless real. The problem cannot be explained away however simply because agreement cannot be obtained relative to the phenomenon itself its nature or its locus. In a practical sense everyone particularly a pilot after a long flight over difficult terrain and in adverse weather conditions understands in a subjective sense what is meant by the words nervous and physical exhaustion and fatigue.

In this discussion an attempt to be practical is made since the flight surgeon is always faced with practical problems. An operations manager or flight officer for example may approach him with such questions as these. The pilots on certain routine operations are returning to their bases completely exhausted is the flying time too long? Do they fly at too high altitudes without oxygen? Or is there something in the cockpit that affects them adversely such as vibration noise or poor illumination? Or again Captain Jones does not seem to be himself these days. He has gone stale. He is tense nervous and irritable and shows poor judgment in making decisions while in flight. He used to be one of the ablest pilots in the flight group but his flying is no



longer trusted. Should he be grounded or sent away on a vacation? Finally, in the daily press are recorded accidents attributed to "pilot error." In the early stages of the war, the British pilots were evidently losing more planes in landing accidents on returning home from fighting abroad than during actual combat with the enemy. In civil aviation in this country, a large percentage of the accidents (often estimated at 80 to 90 per cent) are ascribed to pilot error. Do these pilots become so exhausted that their judgment is faulty when they make decisions or land? Do latent or minor visual defects in acuity, in night vision, in space perception and in sensory-motor performance become manifest or acute after long hours of fighting under intense emotional strain?

Since one cannot control and measure all the variables involved, the answers to such questions are indeed difficult. In a short discussion, one can hope to indicate only some of the more important contributing factors involved in pilot fatigue. Only brief mention is made, therefore, of the so-called "locus" of fatigue and of the accumulation of fatigue substances. Emphasis is placed on the variations in energy resources, such as oxygen and sugar, and, more especially, on several major contributing factors to fatigue, such as worry, personal maladjustments, lack of exercise, the effects of high altitude, poor selection of food, the excessive use of alcohol and tobacco, and certain factors in the cockpit of an airplane, such as noise and vibration. Finally, a study of fatigue in transoceanic airmen is discussed.

### **Locus of Fatigue**

For many years, physiologists have attempted to locate fatigue in certain parts of the body—in the muscle itself, the nerve end plate, the nerve fibre, the synaptic junctions of the cortical cells of the brain. Numerous experiments have shown that the nerve fiber is almost indefatigable. These phenomena are demonstrated to students of physiology with the classic experiment involving a nerve-muscle preparation. A frog muscle, with its efferent nerves, is isolated; the nerve is stimulated until the muscle ceases to contract. Then, if the muscle is stimulated directly, it may react almost as vigorously as before. If the nerve is given a normal supply of oxygen and stimulated alone, it will continue to transmit impulses more or less indefinitely. By such procedures, attempts have been made to demonstrate the relative efficiency of the nerve and the muscle and the possible location of fatigue in the nerve end plate or the synapses.<sup>4</sup> Although one can demonstrate that certain muscles are subject to loss of efficiency in ergographic studies, this sheds little light on the fatigue problem in aviation, in which the pilot's gross musculature



is not used excessively. Studies of isolated nerve fibers have proved to be equally inconclusive concerning the basis of fatigue. Except for the role of oxidation in the efficient functioning of the nerve tissue, therefore, the implications of these experiments for pilot fatigue are not very direct.

It may be that the psychologists who have stressed the role of the higher cortical levels have more information to offer regarding pilot fatigue. They speak of mental blocking and they have demonstrated that, under certain conditions involving stress, there is a loss of efficiency in mental tasks.<sup>5</sup> This is especially true of the tasks that involve the more complex cortical functions such as memory and delicate judgments of discrimination and choice.

In the field of vision, in which the processes involved are concerned essentially with minute muscle or nervous tissue, objective data on visual fatigue are very inadequate and inconclusive. Many authorities believe that the frequency with which ocular defects are observed in children (often estimated at 40 per cent) and in adults is directly related to the various strains imposed on the eyes in modern life. Unfortunately, however, little is known about the basic causes of these abnormalities or of the contributing factors to visual discomfort or loss of efficiency in visual work. Even in an applied problem in industry, such as the amount of illumination necessary to prevent visual discomfort, one finds a wide divergence of opinion among equally prominent authorities. The problem is complicated by the nature of the visual mechanism itself—that is, the retina is an extremely complex organ being essentially an extension of the brain. It involves only a small amount of tissue, it adapts itself readily to changes in the environmental setting and it apparently recuperates rapidly from ordinary stresses. In fact, many believe that the retina is indefatigable. Experiments dealing with the ocular muscles used in reading show that they are not easily subject to a work decrement. Carmichael and Dearborn<sup>6</sup> have failed, for example, to find evidence of fatigue of the muscles of the eye during six hours of continuous reading. The records were made by attaching electrodes to each side of the eye so as to record the action potentials of the ocular muscles during reading. Although the basis of visual fatigue is not clearly understood, it is essential to protect the pilot from variables known to accentuate visual discomfort, such as excessive glare from the clouds or sun reflections from metal surfaces on the plane and poor illumination in the cockpit.



### **Accumulation of Toxic Substances**

For many years, physiologists have attempted to associate fatigue with certain substances in the blood. At one time, many believed that lactic acid was the long-sought toxin.<sup>7</sup> Dill and his colleagues<sup>8</sup> have shown that the accumulation of lactic acid is related to fatigue but that, as an explanation of this phenomenon, such accumulation is more restricted than observers at first believed. Their experiments have revealed that the concentration of lactic acid in the blood remains a useful index to the degree of fatigue in one sort of activity, for example, that in which either the oxygen supply is deficient or the oxidative mechanism of the muscles is not competent to meet the demands placed on it. In studying a group of persons varying in athletic fitness or training, they<sup>9</sup> observed that in a famous Marathon runner there was no accumulation of lactic acid. In several untrained subjects, however, the accumulation of lactic acid was very great. Those who were well trained were able to carry out the tasks with ease, whereas those in poor training who created large amounts of lactic acid were severely handicapped. The magnitude of the increase in lactic acid was closely related to the degree of fatigue, as indicated by other objective measures, such as the heart rate, respiratory rate and blood pressure, and by subjective evidence. That lactic acid is not the only factor was evidenced by the fact that many track records are broken by athletes in successive heats with lactate in their blood. Furthermore, industrial workers doing heavy work, as well as miners at high altitudes, have been observed to have normal values for lactate in the blood. Other substances have been proposed as toxic factors in fatigue, such as ammonia and histamine, but further evidence is required to establish these theories.

### **Exhaustion of Energy Reserves**

A great deal has been written about the exhaustion of such energy reserves as sugar as a causative factor in fatigue. Experiments indicate that in very exhausting work—in a Marathon race or industry—the administration of glucose is of considerable value in maintaining efficiency. In work with a bicycle ergometer, Christensen et al.<sup>10</sup> observed that a very low blood sugar was associated with exhaustion and even the sensory impairment. These effects were rapidly counterbalanced by the ingestion of glucose, and the subjects could continue the work for an hour or more. In heavy work, the preferred fuel is carbohydrate. If heavy labor is continued for a long time without food, the diminishing reserve of carbohydrate is associated with a falling respiratory quotient.



a reduction in efficiency a decreasing concentration of blood sugar and the appearance of acetone in the urine. Subjects in poor physical condition have low reserves of energy and a reduced capacity for transforming energy. Unfitted or untrained factory workers, therefore, may benefit from glucose or other readily available fuel taken between meals. They seldom work hard enough to exhaust their stores of sugar and other reserves. The effects are chiefly on the central nervous system. It is difficult to explain the reports of benefits from the ingestion of glucose in more sedentary occupations.<sup>11</sup> During very long and exhaustive flights at high altitudes pilots are benefited by taking between meals such foods as glucose, which is easily assimilated. From evidence obtained during heavy muscular work, however, it is difficult to understand how a pilot could consume his entire carbohydrate reserve since the amount of gross musculature involved is so small. It appears therefore, that the exhaustion of energy reserves in a pilot could hardly be an important causative factor in fatigue except under special circumstances.

In the field of mental work it is even more difficult to explain how the ingestion of sugar might counteract the effects of fatigue, although it is well known that the nervous system is primarily dependent on carbohydrate for fuel. The metabolic cost of mental work is very slight indeed. Laird's<sup>12</sup> report that fatigue in students doing simple psychomotor tests is modified favorably by the ingestion of certain sugars such as maltose has not been confirmed by other workers. In carefully controlled experiments on the metabolic cost of mental work Benedict<sup>13</sup> found that sustained mental effort for several hours required only the number of calories in half a peanut. Other experiments have shown that in mental work it is not the involvement of the nervous system that increases oxygen consumption but the musculature and other parts of the body associated with attention and sustained concentration. Hence the fatigue from mental work is due in part to the increased muscular tonus associated with sustained attention.

In spite of negative findings in studies of mental fatigue everyone is aware that subjectively it is a real phenomenon. Barcroft<sup>14</sup> suggests that mental fatigue like chronic oxygen want, undermines normal self-control with consequent exaggeration of feelings and mental abnormalities. He recalls that after prolonged strenuous work during the war he broke down and cried for no apparent reason as he did at the termination of his six day stay in the low oxygen chamber. It is common for anyone after prolonged mental effort or continuous overwork to be aphasic, quick tempered and lacking in self control to a marked extent. Quite trifling experiences make one furious. Barcroft intimates



that the mentally overworked person who eventually seeks medical or psychiatric advice is possibly suffering from chronic oxygen want. Over-exertion breaks down the tissues, owing to insufficient oxygenation, and a prolonged rest is required before adequate restoration can take place. Barcroft concludes that one cannot at present answer one way or the other the question whether mental fatigue is due to oxygen want. The impairment may be caused by a defect in any link in the oxidation process. But one can state with certainty, he avers, that "a given strain produces a greater degree of mental fatigue, as it would of muscle fatigue, when the oxygen supply is deficient than when it is ample." This observation is of significance for the pilot whose environment is known to be deficient in oxygen.

### **Psychologic Factors in Pilot Fatigue**

Prolonged mental strain, anxiety, worry or fear appears to have a cumulative ill effect. Experimental studies of the increased oxygen consumption during emotional stimulation have given interesting results. Grollman<sup>15</sup> found that disturbances of anger or regret increased cardiac output, pulse, blood pressure and oxygen consumption. Totten,<sup>16</sup> in arousing emotions in the laboratory by electric shocks or loud noises, noted increases in oxygen consumption of from 0.5 to 25 per cent with the Benedict respiratory apparatus. The organism, however, can readily adjust itself to these temporary emotional situations. The cumulative ill effect of emotional and mental conflicts of a personal nature or of the strain involved while flying continually under adverse conditions gives rise to pilot fatigue, so-called "staleness" or a cumulative and permanent loss of alertness and efficiency.

In World War I, chronic fatigue or "flying stress," as it was often called, was not uncommon. Birley<sup>17</sup> describes a typical picture of a stale flyer in the Royal Air Force as one having lost keenness and become discouraged and uncertain of himself in the air:

He loses flying judgment and has to force himself to go into the air. He is irritable, short of breath, and he attributes his condition to trivial causes. He sleeps less soundly and dreams of unpleasant flying experiences. Various kinds of mental conflict, such as indecision concerning the desire to fly and feeling unequal to the task, lead to complications involving loss of nerve and morale, at times suggesting the beginning of an anxiety neurosis. As his condition develops, he is eventually grounded, not only temporarily but permanently. The rate of the onset is gradual and is associated to some degree with the respiratory condition of the flyer. The first symptoms show an altered condition of the tone of the respiratory center of such kind that the regulation of breathing is no longer normal. There is also a loss of control in the voluntary system, lessened force of cheek and mouth muscles, and loss of tone in the stomach and bladder walls. Frequently, there is slight incoordination of the finer muscular movements and noticeable tremor of the finger and tongue.



All these symptoms suggest a similarity to the person in ordinary life suffering from overfatigue and bordering on what is commonly called a nervous breakdown. These same ailments are often appearing in the present aerial war.

This problem has been discussed by Armstrong<sup>18</sup> under the terminology of aeroneuroses. In his opinion, this illness is a chronic functional nervous disorder associated with flying. The pathogenesis consists of long continued and profound emotional stress related to fear of accidents, economic and social insecurity and, possibly, nerve tissue destruction producing general irritability, gastric disturbances, insomnia, sensory and motor hyperactivity and a deterioration of the higher nerve centers. This disorder is more frequently encountered in military than in civil aviation. In any large group of pilots however, one is apt to find both borderline and acute cases. One of the chief functions of the flight surgeon is to know the airmen well enough so that they will discuss their emotional problems freely and openly. Pilots who are emotionally maladjusted whether the cause be an unhappy marriage, finances or other troubles, are in danger in the air and should be grounded until their difficulties are straightened out.

If pilots are emotionally well adjusted, one might expect their acclimatization to high altitude to be more efficient because the sympathico-adrenal system in Cannon's<sup>19</sup> terminology is involved in emotional situations as well as in acclimatizing to a lack of oxygen. If the sympathico-adrenal system is impaired or inefficient owing to chronic emotional stress one might expect poor acclimatization to high altitude in some what the same way that emotion may interfere with the digestion of food. Cannon demonstrated that if cats became excited or struggled during an experiment, their ability to withstand oxygen deficiency was remarkably lessened. McFarland and Barach<sup>20</sup> observed that neurotic patients as well as those suffering from chronic nervous exhaustion, were more sensitive to oxygen deprivation than control subjects. This was manifested by greater frequency of fainting or collapse when they were placed in chambers deficient in oxygen which thus simulated high altitude. It is commonly observed in the commercial air transport planes that passengers who are very nervous are frequently the first to become air sick or notice the effects of the altitude. A pilot may expect to find his ceiling becoming progressively lower if he is worried or emotionally upset.

Thus far, the difficulties involved in attempting to locate the phenomenon of pilot fatigue in any particular organ or toxin have been stressed. The nervous system and muscles do not seem to be subject to fatigue.



except under very limited conditions of oxygen lack, low blood sugar or excessive accumulation of lactic acid. Since the pilot's life is, for the most part, a sedentary one, with only partial use of the gross musculature, it is unlikely that the reserves of energy would be exhausted. The emphasis has been placed on psychologic factors, such as worry and mental and emotional conflict. In addition to the emotional factors, lack of exercise, the effects of lack of oxygen at high altitude, the wrong kind of diet and the excessive use of alcohol and tobacco are major contributing factors.

### *Exercise and Pilot Fatigue*

The trend of civilization from the earliest times has shown a close relation of the fitness of man and animals to their environment. If the environment changes, the animals must change to meet the new conditions. Airmen, to meet the requirements of prolonged sojourns at high altitude, must therefore attempt to adapt themselves so as to live comfortably and remain efficient under these conditions. In man's fight with the environment, the neuromuscular mechanisms have played a vital role. Under modern urban conditions, the muscles, lung surface and heart tissue are far in excess of what is needed for sedentary life. Unless the extra tissue is called into play, it atrophies and becomes a source of weakness. The highly trained athlete who suddenly stops training after leaving college is especially vulnerable to organ dysfunction. Large parts of the central nervous system are set aside for muscular activity, and this reserve must be used if it is not to become a source of danger.

The increase in emotional and mental disorders may also be related to the very great changes in modern, as compared to primitive, life. The glandular changes known to occur under emotional excitement, such as fear and anger, equip the organism for a struggle.<sup>21</sup> The secretion of adrenaline from the adrenal glands causes the blood pressure and heart rate to increase; the blood is directed from visceral activity to the muscles and brain; there is an increase in the rate and depth of breathing and a dilatation of the bronchioles of the lungs to facilitate the transport of oxygen to the arterial blood; the glycogen stored in the liver is released to provide extra fuel for the muscles; the pupils are dilated; and there is an increased rate in the coagulation of the blood in case of injury. All these changes have great significance in the survival of the organism in the event of a struggle. Under civilized conditions, however, there is less need for these physiologic changes. Continual emotional stress without overt activity may therefore have a cumulative ill effect



on the efficiency of the organism in meeting situations involving stress. In piloting an airplane there may be continual emotional stress especially in adverse weather and over difficult terrain without an excessive amount of physical exertion. At the end of the flight the pilot should attempt to obtain some form of physical exercise to keep in condition.

There is some evidence of concrete advantages from routine exercise for airmen. The pilots in the Royal Dutch Airlines apparently derived benefit from routine gymnastics during a week following long flights from the Continent to the Dutch East Indies and return. In a study of 50 Pan American Airways pilots in Miami Dr. Jolin T. Macdonald<sup>22</sup> observed an increase of four points in the Schneider index by moderate yet routine exercise over a period of several months. The benefits derived from such procedures were especially apparent in the older pilots. Further controlled studies are indicated to demonstrate the value of regular exercise for airmen.

It is a common experience to find that a man in poor physical condition is easily exhausted by mental and physical exertion; he is irritable and likely to have morbid thoughts, petty ailments and poor judgment; he may have a sallow complexion and dull eyes and he frequently complains of constipation, headache, nervousness and insomnia. On the other hand, it is equally common to observe in a man of good physical condition evidences of mental and bodily vigor such as alertness, cheerfulness, high morale, healthy complexion and capacity for arduous mental and physical work. It is believed that these two conditions are but the outward expression of physical differences within the body. There are no tests available to predict whether a pilot will make a serious error of judgment or lose emotional control in a crucial situation. For the most part, however, it is safe to say that errors of judgment or emotional confusion are the reflection of a poor or rundown physical condition. For this reason, a pilot must maintain a high degree of physical fitness.

#### **Effects of Altitude in Accentuating Fatigue**

It is well known that the important reactions in the human organism encountered at high altitude are due to the diminished partial pressure of oxygen.<sup>23</sup> There is no storage of oxygen in the human economy as there is for other chemical substances like sugar and calcium, although the release of red cells by the spleen and bone marrow may be considered a reserve of oxygen in a limited sense. The blood is really the only storehouse and its capacity is very limited. Hence the body lives a hand-to-mouth existence and is dependent on a constant supply from the atmosphere. At 10,000 feet a given breath of air supplies only



two thirds as much oxygen as at sea level, and at 18,000 feet only half as much.

The average unacclimatized passenger is apt to complain of certain physical discomforts while flying above 10,000 to 12,000 feet. In an extensive investigation carried out in experimental chambers at sea level and during prolonged flights at high altitude, the following reactions have been recorded voluntarily by the subjects and passengers.<sup>24</sup> The list is arranged in order of frequency and severity: slight frontal headache, which may become worse with increasing altitude; dizziness or vertigo on moving suddenly or irregularity in breathing and shortness of breath on exertion; digestive disturbances, especially gas in the stomach and in the intestines, and indigestion or slight nausea; slight sensory impairment on moving too suddenly, especially noticeable in alterations in vision; a tendency toward sleepiness or lethargy; and a sense of exhaustion and fatigue on exertion.

The response of the average passenger or pilot to high altitude may be influenced by a large number of variables. Since these factors are so essential in determining the altitudes where oxygen should be used and in answering other practical problems in civil aviation, a number of the more important ones are listed below. All these variables are either directly or indirectly related to the problem of pilot fatigue.

*Height attained.* There are great individual differences among the specific altitudes where the effects are first noticeable or become marked. Some persons may be affected at 8000 feet, and others at 16,000 to 18,000 feet. In a group of over 150 unselected subjects varying in age and physical fitness, in low-oxygen chambers at sea level during exposures of two to four hours' duration, the initial effects were significant in the average person at from 10,000 to 12,000 feet.<sup>24</sup> The effects may become quite marked at 14,000 to 16,000 feet and dangerous at 18,000 to 20,000 feet. The upper limit of consciousness in unacclimatized man appears to be about 25,000 feet.

*Rate of ascent.* In a series of experiments on rate of ascent, it was observed that if the high altitude is attained gradually,—that is, in an hour,—the effects are considerably less serious than during an ascent to similar altitudes within fifteen minutes. In a number of subjects who showed very poor responses following rapid ascents to 16,000 feet, a satisfactory acclimatization was made during repeated experiments in which the ascent was extended over one hour and fifteen minutes. During a slow ascent, the mechanisms of adjustment to the reduction in oxygen pressure have an opportunity to function. On the trans-Pacific flights, where from one to three hours may elapse before the



ship is leveled off at the desired altitude, slow ascents are physiologically favorable to the passengers and flight personnel<sup>25</sup>

*Length of exposure* Moderate altitudes of 6000 to 10 000 feet may be tolerated over long periods (eight to fourteen hours) without apparent ill effects. This does not seem to be so at 12 000 to 14,000 feet. Although the mechanisms of acclimatization may be effective at moderate altitudes, the opposite appears to be true at higher altitudes. Deterioration may set in, and the physical symptoms during the flight may be quite unpleasant. Older pilots find it advantageous to use oxygen at and above 9000 feet for flights of more than two or three hours duration.

*Amount of physical exertion* The effects of high altitude tend to be accentuated during exercise. This is of particular significance in stewards, whose chief activity involves the preparation and serving of meals and making up berths while in flight. On this account, the other members of the flight crew should not make excessive demands on the steward during flights at high altitudes. Care should be taken not to make too sudden movements or to stoop over too quickly because of cerebral anemia or lack of blood and oxygen in the brain and the increased susceptibility to fainting. Passengers should be urged to remain quietly seated following a meal at high altitude so that the blood will not be diverted from the digestion of food to the muscles. Also, the airmen might find it advantageous to arrange their meals aloft so as to relax for a short time following a meal before going on duty again.

*Roughness of air and sudden movements of plane* Air sickness becomes greatly accentuated at high altitude. Because of the combined effects of oxygen lack and rough air in interfering with the digestion of food, special precautions should be taken in the kinds of food ingested while one is flying under adverse conditions at high altitude.

### Importance of Pilot's Diet

Among the factors that may affect the efficiency of a pilot, no one is more significant than his food. This is especially true during flying because of the effects of oxygen lack on digestion. Several controlled experiments have been carried out on the effects of reduced oxygen pressure on the digestive processes. In studies with dogs, Delrue<sup>26</sup> observed a marked diminution of gastric secretion, lasting from two to three days, in animals taken from a low to a high altitude. Van Liere, Crisler and Robinson<sup>27</sup> found that the emptying time of the stomach was prolonged in proportion, so that at 20 000 feet the dogs had food in their stomachs twenty four hours after ingesting it. In additional experiments on dogs, these workers<sup>28</sup> found that oxygen deprivation altered the



hunger contractions of the animals, so that, under acute conditions and also following the experiment, the contractions were considerably diminished.

These findings on animals were then checked on 8 medical students in a low-pressure chamber.<sup>29</sup> A barium meal was given, so that fluoroscopic views of the stomach movements could be followed. The degree of retardation of the emptying time of the stomach varied roughly in proportion to the degree of oxygen deprivation. The altitudes where the first changes were noted for the average person at rest were between 6000 and 8000 feet. These and other experiments indicate that, although the effects of the reduced oxygen pressure at moderate altitudes are not severe, there is ample evidence that both the airmen and the passengers should take precautions in the amount and kinds of food ingested aloft.

At high altitudes, the pilot or passenger may become uncomfortable or distressed by abdominal bloating due to the expansion of gases in the intestine during the ascent. It is well known that the gases accumulated in the digestive organs expand as the external pressure falls, so that at 18,000 feet,—that is, half an atmosphere of pressure,—the gases in the digestive organs expand to double their volume. This may lead to an unpleasant pressure on the abdominal wall and diaphragm, thus decreasing the normally available space of the thoracic cavity. When gas forms continually in the stomach or intestinal tract, it may be the result of either excessive worry, fear or other emotional disturbances that interfere with the digestive processes, as explained above, or a diet too rich in foods that are easily fermented, such as green vegetables and certain carbohydrates.

In general, it may be said that the most desirable diet for the airman or passenger previous to a flight or while in the air is one of high caloric value, which is easily assimilated. Carbohydrates, such as glucose and cane sugar, and the products derived therefrom are highly recommended. On the eve or day of a flight, only a limited amount of leguminous or green vegetables and fruits should be eaten. Highly spiced or greasy foods should very definitely be avoided, especially cellulose, the skeleton of most plant structures and of plant cells. Cellulose is also found in other portions of starch grains and leguminous vegetables, such as beans. By diminishing the formation of intestinal gases by the control of the kinds of goods ingested before or during a flight, the pilot is certain to be more comfortable and more efficient while performing his duties.

Interesting results have been obtained in the Pan American Airways System in special cases of fatigue and chronic minor illnesses in which



pilots have supplemented their diets with vitamins and minerals. This has been particularly true in certain pilots flying in Alaska or Central and South America, where fresh vegetables and other essential food stuffs have been lacking in their diets. A study of night vision in pilots with the Hecht adaptometer was made on 200 pilots<sup>24</sup>. Two marked cases of vitamin A deficiency and 7 cases of borderline or questionable abnormality were observed. Controlled studies are being made at present on large numbers of military and civilian pilots. A more exact indication of the extent of dietary deficiencies should be available in the near future. Better objective tests, which might reveal deficiencies of each vitamin or mineral, are needed.

Another major consideration in the diet of airmen and passengers is the quantity of food to be taken previous to and during flight. Under most conditions of modern life when muscular activity is limited, the average person probably eats far too much. The sleepiness and lethargy following an excessively large meal are well known to everyone. In view of what has been stated above about the formation of intestinal gases at high altitude as well as the general slowing up of digestive processes and the slower movement of food through the intestinal tract, the amount of food ingested before and during a flight should be greatly curtailed. There is no question that mental and physical efficiency, as well as general comfort during a flight, can be greatly influenced if smaller amounts of the right kinds of food are eaten.

#### Effects of Alcohol

A large number of experiments on the psychologic effects of alcohol show that it decreases efficiency because of its apparently depressant influence on the nervous system. The initial stimulation is probably due to overcompensation on the part of the organism to ward off the depressing effects. Even small doses of alcohol have been shown to decrease reflex irritability, slow up muscular movements and reaction time, raise sensory thresholds, impair attention and concentration and after a time, reduce the natural spontaneity of mental functions<sup>30</sup>. Experiments on both mental and physical fatigue reveal that alcohol hastens loss of function and impairs efficiency. The improvement so often noted is due to abolishment of the sensations of fatigue. In athletics, such as in crew or track, the transport of oxygen from the blood to the muscles is impaired, and it is for this reason that even small amounts of alcohol are detrimental and cut down performance by the fraction of a second necessary to win a race.

Recent research on the effects of alcohol has revealed a number of



interesting facts for pilots and air passengers. Possibly one of the most direct effects of alcohol on the organism is that of diminishing the utilization of oxygen in the tissues. There is a close similarity between the behavior of a person suffering from acute oxygen deprivation on a mountain, in an airplane or in a low oxygen chamber at sea level and that of a subject under the influence of alcohol. The effect on the nervous system under both conditions is essentially the same—that is, a deficiency of oxygen is delivered to the tissue. At high altitude, there is a deficiency of oxygen in the inspired air, and under alcoholism there is a hindrance in the transport of oxygen from the blood to the tissues.

The frequent references to the similarities in behavior between the effects of alcohol and of oxygen want (anoxia) and the fact that acute alcoholism could be counteracted by breathing excess carbon dioxide led McFarland and Barach<sup>31</sup> to analyze the concentration of alcohol and lactic acid in the blood following the ingestion of standard amounts of alcohol in an oxygen chamber filled with air and at other times with excess oxygen (50 per cent) and excess carbon dioxide (2 to 5 per cent). The experiments showed that on the average both the blood alcohol and lactic acid were diminished during the breathing of excess oxygen and carbon dioxide as compared to the breathing of air. On the other hand, the alcohol was oxidized more slowly and the subjective effects accentuated when air deficient in oxygen was breathed. The experiments were repeated at 17,500 feet and 12,220 feet in the Andes, with similar results.<sup>32</sup> The significance of these findings for airmen is obvious. The effects of alcohol are greatly accentuated at high altitudes, and efficiency following the ingestion of alcohol is therefore impaired proportionally. The passenger who boards an airplane after drinking heavily may fall asleep quickly and forget his fears and worries. If the air is rough, however, he usually awakes and is more subject to airsickness. The pilot at that time, on the contrary, must be alert and efficient, and nothing should be involved to impair his nervous functions during the flight.

#### Effects of Tobacco

There are very few carefully controlled studies of the effects of smoking, and even less information dealing with the effects of tobacco at high altitude. Modern advertising has tended to distort the facts regarding the effects of tobacco. The evidence from reputable university laboratories does not uphold the contentions frequently made that one brand of cigarette causes less acidity than another, or that any "lift" is due to an increase in blood sugar. It is obviously absurd that smoking necessarily goes with being a good athlete, explorer or aviator, as many cigarette advertisements imply.



The stimulating effect of tobacco is due to the nicotine, which is an alkaloid. Nicotine is poisonous, and in small quantities has an effect similar to other alkaloids (morphine, strychnine and cocaine). The commonly alleged soothing effects of smoking tobacco are due primarily to the nicotine. A number of carefully controlled studies indicate that smoking gives rise to the following reactions in the organism, largely through stimulation of the autonomic nervous ganglia: an increase in pulse rate, especially noticeable when one smokes before breakfast, an initial rise in systolic blood pressure, followed by a fall immediately after the smoking period, which may account for the dizziness often noticed by the inexperienced smokers, constriction of the blood vessels, particularly in the periphery of the body, a slight impairment in keenness of vision—since the eye is the most sensitive of the special senses, these effects are manifested in visual functions more readily than in hearing, inhibition of digestive movements of the stomach—it is from this effect that the smoker may temporarily allay his hunger, effects on the surfaces of the lungs, which give rise to breathlessness on exertion. There is some evidence that the carbon monoxide from smoking affects pilots adversely, although the amounts are small they are believed by many to be damaging at high altitudes and relatively innocuous at sea level.

During World War I, a series of studies was carried out on aviators relative to the effects of smoking.<sup>33</sup> The results indicated that in 75 per cent a single cigar or the inhalation of one or two cigarettes had definite though temporary effects on vision and caused an increase in pulse rate and a rise in blood pressure. The visual effects were manifested in terms of reduced visual acuity and ocular muscle balance. Only a few nonsmokers were studied. In these cases, some giddiness occurred at eighteen to twenty minutes from the start, and was accompanied by slight nausea.

It is therefore obvious that excessive smoking has a detrimental effect on the pilot's acclimatization to high altitude. It tends progressively to lower his ceiling, just as it would impair his performance in a track or crew race at sea level, owing to the unknown effects on the lungs and circulation. It also impairs his digestive processes and the assimilation of food. The airman is warned against smoking before breakfast and against the excessive inhalation of cigarette smoke at all times.

#### **Effects of Noise and Vibration and Other Variables in the Cockpit**

Certain variables in the cockpit of an airplane are contributing factors to pilot fatigue. These effects are less extreme in modern civil



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aircraft than in military planes. It should be kept in mind, however, that the noise and vibration in the cockpit are much greater than those in the passenger compartments of most civil aircraft.<sup>24</sup> Unfortunately, there are few controlled studies dealing with the effects of noise and vibration in aircraft on pilot performance and fatigue. Many pilots believe that these are significant factors, especially in flights of extended duration. A number of fatiguing influences that should be carefully controlled are as follows: the pilots' seats should be free of vibration and located conveniently near the controls and instruments; the navigating tables should be cushioned, to prevent excessive vibration; the cockpit should be well illuminated at night; radium paints should be eliminated on the dials because of the possibility of noxious effects from the radium; metal surfaces, which give rise to glare, should be eliminated; attempts should be made to reduce the static in the ear-phones; and the ventilation and temperature should be well controlled, to avoid extremes. All these variables may contribute to pilot fatigue individually or collectively. The flight surgeon should study every factor that affects the health or efficiency of the pilot. Most of these adverse conditions can be corrected by aeronautical engineers.

#### **Experimental Studies in Trans-Pacific Flights**

A study of fatigue in transoceanic airmen was carried out on a routine flight of the Pan American clipper between Alameda, California, and Manila, Philippine Islands, and return, to analyze the fatiguing effects of prolonged flights at altitudes averaging 9460 feet on 17 airmen and 11 passengers.<sup>25</sup> The total flying distance of 14,141 nautical miles involved one hundred and twenty-two and one-half hours in the air. A series of physiologic, biochemical and psychologic studies were made at the various island stations. The following conclusions may be drawn from the data obtained on these airmen and passengers:

The subjects, both airmen and passengers, maintained a high degree of neurocirculatory efficiency through the flight, as judged by the individual items and composite score of the Schneider index. When the test was given in the basal state,—that is, before ascent,—none of the airmen tested below +7, a score frequently related to a significant degree of fatigue or unfitness in aviators. Of one hundred and forty-two tests in the basal state, only 8 subjects tested below +10, the average being +13, which is close to the mean of +14.8 for college athletes. The average basal state (fifty-four tests) was +11.5, only three tests falling below +7 throughout the flight. The mean score for the group at high altitude was +10.8. In a total of ninety-six tests given at a mean altitude of



9500 feet only four fell below +7

There appeared to be a general tendency toward low blood pressure as the flight progressed that was similar to the blood pressure observed in acclimatized workmen at high altitudes in the Andes. Six of the 8 airmen (the mean age for the group was thirty two years) had systolic blood pressures below 110. The initial response to altitude usually showed an increase in pulse rate and an increase in systolic blood pressure followed by a well controlled fall to normal values if the subject remained at rest.

As the flight progressed the pulse rate tended to show a greater increase after exercise and to take longer to return to normal. As might be anticipated this was also true at high altitudes.

There was a consistent decrease in the Schneider indexes in Manila. This was related to the increased pulse rate caused by the high humidity and temperature of that region. After the subjects rested two days in Manila and slept in air conditioned quarters there was an improvement in the Schneider indexes. After a rest period of one week in Honolulu there was a slight decrease in the mean Schneider index for the 8 airmen.

There was a tendency toward polyuria in these airmen as commonly observed in athletes previous to competition particularly in those who shared the greatest responsibility in handling the ship. As the flight progressed and the airmen became acclimatized the polyuria diminished. The partial pressure of oxygen and carbon dioxide in the alveolar air and arterial blood of these airmen was similar to values considered normal for acclimatized men at similar altitudes and suggested that the added burden of flying the ship had no impairing effect on the respiratory mechanism. The alveolar partial pressure of oxygen in the acclimatized airmen averaged 4.8 mm. higher than in unacclimatized passengers during rapid ascents to similar altitudes.

There was an increase of approximately 10 per cent in the red cell counts at high altitudes. After five or six days at sea level the counts returned to more normal values in 9 of the 11 airmen. Even after eleven days at sea level however 2 subjects had counts of 16 per cent and 18 per cent above the usually accepted value of 5 000 000 for men at sea level this suggested a more stable acclimatization in these men.

The normal nonprotein nitrogen blood sugar and cholesterol values suggest that there was no serious upset of the protein carbohydrate or fat metabolism of these airmen. The normal values for blood sugar indicate that there was no intense emotional excitement and increased secretion of adrenaline during flight.

There were only slight alterations in the visual and mental tests which



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consisted primarily of measures of quickness of reaction time for meaningful material, close attention to detail and memory. The tests were given at 10,000 to 12,000 feet, and compared with sea-level norms.

In general, the conclusion may be drawn from this investigation that the 17 airmen studied during typical trans-Pacific operations became acclimatized to the high altitude and maintained a high degree of mental and physical efficiency throughout the flight. The 11 passengers of average age and fitness studied, although not manifesting the same degree of acclimatization as the airmen, showed no objective signs of fatigue or physical distress.

### **Summary**

In this discussion of fatigue in aviation, an attempt is made to analyze some of the more important contributing factors to pilot fatigue. It is shown how the attempts to locate fatigue in certain tissues or organs have not proved to be very revealing in solving practical problems related to subjective fatigue and exhaustion. Likewise, the search for a fatigue toxin, such as lactic acid, has brought to light many significant variables related to fatigue, but the relations have been more restricted than was at first expected. Furthermore, it is shown that a pilot whose muscular activity in flight is limited could hardly exhaust the energy reserves sufficiently to explain the fatigue and exhaustion often observed in airmen. The essential variables in the phenomena of acute or chronic pilot fatigue and exhaustion are ascribed to psychologic factors such as emotional stress, regardless of whether it is related to adverse flying conditions, fear of accidents, economic and social insecurity, and unhappy marital adjustments. The major portion of the discussion is related to an analysis of certain contributing factors in pilot fatigue, especially lack of exercise, the reduced tension of oxygen encountered while in flight at high altitudes, the poor selection of food and the excessive use of alcohol and tobacco. Also, certain physical variables in the cockpits of airplanes are discussed as other contributing factors to fatigue, such as noise, vibration, poor illumination, glare, static from the radio and poor regulation of the ventilation and the temperature. Finally, the results obtained in a study of transoceanic airmen are analyzed to show the effects of long flights at moderately high altitudes.

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# SUDDEN COMPRESSION INJURIES OF THE ABDOMEN AT SEA

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In contrast to the extensive literature on blast injuries of the lung, reports on the effect of sudden compression of the abdomen are few and brief. It has been recognized in this, as it was in the last war, that compression or suction waves set up by the detonation of high explosives on land or at sea cause, among other lesions, bleeding into the lungs and abdominal viscera. Atkins (1940) describes the cases of three patients, injured by depth-charge explosions while they were swimming, who came under his care suffering from peritonitis after the Dunkirk evacuation. All were operated upon: one had a perforation of the ileum three inches above the caecum; the second had a similar lesion in the first part of the ascending colon; while the third showed multiple petechial haemorrhages with oedema in the walls of the intestines but no perforation. The third of these died, but the first two, after suture of the perforations, survived. Atkins says that prognosis in these injuries is usually bad because of associated lacerations of the brain and lungs. Gordon-Taylor (1940) has noted bowel rupture without breach of the skin in shipwrecked men injured by depth-charge detonations. He believes that organisms permeating a contused colon may be the cause of an abscess or even a faecal fistula. Below we record two such abscesses, one pelvic and the other subphrenic, which may have been due to this cause. Gordon-Taylor also describes a group of patients who suffered from severe melaena but recovered without serious complications. We record the cases of seven such patients who developed varying degrees of haematemesis and who all recovered. Wakeley (1941) also has noted compression injuries in sailors.

## Clinical Features

The case histories fall into three groups: (A) obvious abdominal injuries that recover completely without operation; (B) severe injuries, such as lacerations, disclosed at operation; and (C) late complications, such as abscess formation.



It is clear that immediate fatalities are numerous, but we have no data regarding these. This report deals with survivors from a convoy attacked by submarines, and all were rescued by small ships, in which immediate operations such as laparotomy were not possible. We have nothing new to add to the well known principles which enable the surgeon to decide whether he should operate or not in recent abdominal injuries. The happy fact is that, out of ten survivors seen, none recovered without immediate operations, though grave symptoms such as shock, haematemesis, melaena, and pyrexia were present in most.

### Group A

#### Haematemesis; Melaena; Abdominal Pain; Complete Recovery in Seven Patients

The clinical features were so similar in all the cases of this group that the description of only one case is given.

CASE 1.—The patient, an Allied naval officer aged 27, was swimming in the sea after his ship had been torpedoed when depth charges from the sinking vessel which was thirty yards away, detonated on sliding into the water. He felt a "sudden electric shock" but did not lose consciousness, and reached a raft. He was rescued by a small naval ship and walked to a cabin unaided. Within an hour of the explosion he vomited a good deal of blood and developed hiccups and much abdominal pain. When examined by a surgeon lieutenant who had been put on board, the lower abdomen was found to be rigid and tender. The patient was treated with morphine and was allowed fluids. He complained of a good deal of pain in both testicles. The next day he required catheterization, but there was no blood in the urine. Throughout the day he had diarrhoea, with obvious blood in the stools.

Three days later he was put ashore. He was pale and exhausted, his temperature was 99° and his pulse 100. The abdomen was tender, especially in the left epigastrium, but there was no true rigidity, there was a moderate generalized distention and no evidence of free fluid or loss of liver dullness. He vomited twice in the first twenty-four hours, and diarrhoea with melaena continued for two days. The urine was free from blood. The blood count and haemoglobin were normal. Fluids only by mouth, together with tinct. opii, *mxs., t.d.* were given for three days, when the last was gradually built up. Four days after admission there was still tenderness, but the tender areas varied, sometimes being in the left and sometimes in the right epigastrium, occult blood was present in the faeces. He suffered a good deal of pain in the lower part of both sides of the chest and had a little sputum, but there were no notable physical signs, and a chest radiograph taken four days after admission showed no pathological features. A slow recovery, uneventful except for a daily pyrexia of 99° to 100.5° for ten days followed.

In the other six patients of this group the clinical symptoms were very similar, though of varying degrees of severity. Two other patients complained of severe bilateral testicular pain. No patient had blood in



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the urine, and the testicular pain was probably due to compression and not to referred pain.

### **Group B**

#### **Laceration of Ileum; Peritonitis; Compression Injuries of Lungs; Laparotomy and Suture of Perforation; Ether Convulsions; Death**

CASE 2.—A lieutenant of the R.N.V.R. aged 26 sustained injuries when a torpedo struck his ship. He was trapped in a compartment flooded with oil, and was rescued from the water within an hour of the explosion. He was able to walk to a cabin though suffering from severe vomiting. When seen by a surgeon lieutenant four hours after the sinking the pulse was 80 and the temperature 100°; he complained of abdominal pain with tenderness in the right iliac fossa. Twelve hours later the pulse was 96 and the temperature 103°, and he coughed a good deal. He was unable to pass urine, and had severe pain in both testicles. Twenty-four hours after the attack on the ship he was restless, the pulse was 120, he passed blood and mucus per rectum, and coughed up some darkly stained frothy mucus that contained fuel oil. At this time he was in a corvette actively engaged against the enemy, and laparotomy was quite impracticable. Thirty-eight hours after being torpedoed he was put ashore with the diagnosis of "possible rupture of a viscus or subperitoneal haemorrhage." On admission to the hospital he was restless and exhausted, with a temperature of 101° and a pulse of 110. The abdomen was not rigid, but there was considerable tenderness in the right iliac fossa. He was also dyspnoeic. Immediate operation was considered inadvisable because of the patient's poor general condition and the uncertainty of the diagnosis. Resuscitation measures included morphine, a pint of plasma, and 1½ pints of saline and glucose given intravenously throughout the night. A considerable improvement followed, but fifty hours after the torpedoing he presented unmistakable signs of spreading peritonitis in the lower abdomen, and operation could not be deferred. The blood picture was normal and the haemoglobin 90%; there was no blood in the urine. The stomach was washed out and the tube left in place while intratracheal gas, oxygen, and ether were administered (Major T. H. Hobbes, R.A.M.C.). Laparotomy disclosed a small tear in the ileum, about three feet above the caecum, which was closed by Lembert suture. There was a gross distension of the intestines, and early general peritonitis with reddening of the peritoneum and exudate was seen. Many haemorrhages were found in the subperitoneal tissues. As the peritoneum was being opened ether convulsions developed; these were checked by intravenous sodium pentothal (0.5 gramme). On return to the ward the breathing was laboured and much frothy sputum was expectorated, and he died 4½ hours later, oxygen being given continually. A detailed necropsy account (see below) reported the presence of "pulmonary concussion."

### **Group C**

#### **Complications Developing Some Days After Original Injuries**

This group includes the cases of two sailors who survived what were severe original compression injuries, treated by conservative measures, but who developed localized abscesses which were treated successfully by drainage.



**CASE 3 Abdominal Compression Haematemesis, Pelvic Abscess, Testicular Pain**—This patient an A B aged 26 was injured by depth-charge detonations while in the water. He was admitted three days later in good general condition but with much generalized abdominal pain accompanied by guarding below the umbilicus. Temperature 100 pulse 96. Before admission he had had considerable haematemesis but was constipated, an enema shortly after admission yielded a good result and relieved the abdominal pain. He had pain in both testicles and the faeces contained occult and fresh blood. His general condition improved but the lower abdominal pain persisted until the ninth day after admission when he passed mucus. A rectal examination revealed a tender non fluctuant mass in the rectum. A pelvic abscess was diagnosed, this was opened through the rectal wall two days later, when it was soft and fluctuant. Complete relief of symptoms followed and the patient made an uninterrupted recovery.

Salient features of the case are (i) the gradual development of the abscess without alarming symptoms (ii) At no time was there evidence of a serious intraperitoneal catastrophe, the pulse was always under 100, and the temperature was never over 100° nor did abdominal rigidity develop (iii) The total white blood cell count never exceeded 14 000 (iv) The testicular pain (v) It is impossible to know whether the abscess followed a small rupture or was due to perforation of organisms through a bruised segment of intestine.

**CASE 4 Compression Injuries Haematemesis and Helicobacter Pylori Posterior Subphrenic Abscess Drainage, Right Pyothorax, Intercostal Drainage, Rib Resection, Recovery**—This patient an A B aged 30, was admitted on the same day and from the same incident as the preceding patient. For three days at sea he had had persistent vomiting and haematemesis, with diarrhoea and blood in the stools. His general condition was poor, being decidedly worse than that of his colleague and he could retain only food water by mouth. Abdominal pain was general but no area of local tenderness or rigidity existed, there was no general distension and no loss of liver dullness. The pulse rate never exceeded 90 and there was no indication for laparotomy, since the condition was improving rather than deteriorating when he was seen on the third day. Two days later all vomiting had ceased, but diarrhoea continued, with blood in the slate-coloured stools. The abdominal pain and tenderness had decreased. Six days after admission the temperature, which had been in the region of 99°, began to rise and nine days after admission it reached 102°, with a pulse of 90. The white blood cell count was 20 000. Tenderness was present over the liver area and dullness and impairment of breath sounds were detected at the right base. A radiograph showed a raised right diaphragm and there was an abscess cavity with a fluid level (Major W N Brown R A M C). From this abscess foul pus was obtained by needle. Bacteriological examination showed a mixed infection from which non haemolytic streptococci were isolated. Under general intratracheal anaesthesia (Major E Fowler R A M C) a portion of the ninth rib was resected posteriorly, the diaphragmatic and parietal pleura were adherent and transdiaphragmatic drainage of a large abscess was instituted. The abscess drained well but the temperature persisted and physical signs and radiology disclosed a large pleural effusion six days after the first operation. Twenty ounces of thin foul pus was extracted by Potain's apparatus and the next day an intercostal drainage was established as a tension pneumothorax, the result of gas formation had developed. His condition which had been grave improved steadily. Five days after the operation a pint of blood was given and three days later better drainage was effected. Under intratracheal



## *Sudden Compression Injuries of the Abdomen at Sea*

gas-and-oxygen (Major E. Fowler) a portion of the seventh rib was resected posteriorly and closed drainage into water-sealed bottle through a Tudor Edwards tube was carried out. The temperature slowly subsided, and eight days afterwards was normal. The general condition improved and the patient developed a voracious appetite. At the time of writing a tube is still in the cavity and the lung is re-expanding satisfactorily.

Salient features of this case are (i) the initial symptoms and the absence of signs pointing to definite visceral rupture. (ii) The slow development of a subphrenic abscess in a patient in a high Fowler position throughout; this suggests a small laceration or severe contusion of the stomach, duodenum, colon, or liver. (iii) The development of a large pyothorax with gas formation sufficient to cause a tension pneumothorax, and its satisfactory relief by drainage.

### **Pathology of Sudden Abdominal Compression**

Lacerations do occur, but in many survivors the main feature is sub-peritoneal haematomata. The following necropsy report is given because it represents a picture of a severe case in which lung "blast" coexisted. It must be realized that in the other nine patients in this series the clinical feature of pulmonary concussion was not present, and it is probable that in "blast" injuries at sea the abdomen is affected more than the chest, and in this way contrasts with the picture seen in the blast injuries of air-raid casualties. In this respect it is important to note that the report given below refers to a patient damaged by torpedo explosion while he was in an enclosed space and not to a sailor injured by depth charges as he was swimming. The casualty in the water may well escape pulmonary concussion because the concussion wave acts chiefly on the abdomen. The presence of testicular pain in so many survivors is noteworthy in this connexion and is probably due to a direct underwater compression. The absence of external bruising in any patient of this series is striking.

#### *Post-mortem Findings in Case 2, the Only Fatal Case*

*External Appearance of the Body.*—A well-built man. There were no cutaneous or subcutaneous haemorrhages and no superficial abrasions. The recent abdominal surgical incision was healthy.

*Thorax.*—The pleural cavities were normal and did not contain free liquid. There were no haemorrhages in the parietal pleura, but small petechiae were numerous on the surfaces of the lower lobes of both lungs, especially the right. The trachea and bronchi were filled with frothy blood-stained mucus. The lungs were engorged and oedematous. There were many small haemorrhages, which were noticed only after fixation of a portion of the lung tissue. The heart and pericardium were normal and did not show any evidence of blast injury.

*Abdomen.*—The peritoneal cavity contained about a pint of blood-stained turbid fluid, and there was an acute diffuse fibrinopurulent peritonitis. No haemorrhages were present in the parietal peritoneum, but the visceral, especially that covering the distal loops of the small intestine, was studded with small haemorrhages, most of which were about 0.5 cm. in diameter. They were more numerous in the right side of the abdomen than on the left, and were particularly prominent along the line of attachment of the mesentery. There was



an extensive extravasation of blood in the loose tissue in the vicinity of the hepatic flexure of the colon. The solid viscera were all undamaged. The stomach was engorged and showed pin point haemorrhages on its inner surface. The duodenum was normal. Starting from a point eight to ten feet from the duodeno-jejunal flexure and extending to the lower end of the sigmoid colon where many submucous haemorrhages similar in size to those visible on the peritoneal surface. They were most striking and numerous towards the distal end of the small intestine, where there was a perforation about three feet from the ileo-caecal valve. The degree of haemorrhage around the perforation was not enough to suggest that the latter had resulted from the weakening of the intestinal wall by an extravasation of blood. In the colon many of the haemorrhages were more diffuse, and over a particularly extensive one the mucosa had ulcerated.

*CNS*—The brain was examined and found to be healthy.

During the course of the necropsy the abdominal wall was examined for intramuscular haemorrhages but none was found.

*Histological preparations* were made from the lungs and small intestines. In the lung were found scattered intra alveolar haemorrhages and oedema, separated by patches of normal tissue and areas of congestion with haemorrhage limited by the alveolar walls. In the oedematous patches there were many carbon particles and some basophilic debris. Many macrophages were present dealing with these foreign bodies which were attributed to the inhalation of sea water and fuel oil. Sections of the ileum showed the haemorrhages to be most severe in the submucous and subperitoneal layers of the intestines, but haemorrhages into the muscle layer were also observed. The sections showed that the haemorrhages were more diffuse than was expected from the naked eye appearance of the gut. At the site of the perforation there was haemorrhage into the adjoining tissue, but not a great deal.

#### *Discussion on the Post-mortem Findings*

The patient suffered from ether convulsions during the laparotomy, and at the time of his immersion in the sea he inhaled sea-water, so we must attribute the oedema and congestion of the lungs to these, but the haemorrhages were similar to those which we learnt to associate with bomb blast and which have been described a number of times in the literature.

There have been descriptions in the literature of abdominal injuries as the result of explosions at sea under circumstances similar to those in this instance. The interest of this case is that, when the above post-mortem findings are borne in mind, we can trace the course of events in the other patients of this series who recovered.

#### *Note on Examination of Fish Killed by Depth Charges*

No experiments were carried out to study injuries produced in mammals by underwater blast, but three fishes killed by depth charges were examined. Two of them did not show any naked eye injuries either in the body cavity or in the brain, but one had an extensive extravasation of blood in the posterior part of the coelom. We are indebted to Surgeon Commander Button, R.N., and Surgeon Lieut Commander Carleton, R.N., for obtaining these specimens for us.



# *Sudden Compression Injuries of the Abdomen at Sea*

## Summary

Sudden compression waves produced by torpedo and depth-charge explosions in ten patients showed their chief effects in the abdomen and caused subperitoneal and submucous haemorrhages and lacerations of the intestine. There was clinical evidence of submucous haemorrhages, shown by haematemesis and melaena in ten patients.

Seven patients recovered completely without operation; two others recovered after drainage of a pelvic abscess in one and after drainage of a subphrenic abscess and an empyema in the other; one patient died after an operation for a tear on the small intestine; the post-mortem results are described in detail. In addition to the abdominal injuries blast effects in the lung were seen. In none of the other nine patients were there symptoms or signs of severe blast lung injury, apart from a little haemoptysis in one.

The immediate symptoms after sudden compression were not severe.

The presenting symptoms were vomiting with blood in the vomit, diarrhoea with melaena, and considerable testicular pain in four cases. The last-mentioned symptom was probably due to a direct compression effect. Abdominal tenderness and slight rigidity were present for several days in the nine surviving patients.

There was no external bruising in any patient.

As none of the patients were seen in the first twenty-four hours it is difficult to assess the indication for immediate operation. In the one case with a perforation, the indication of a spreading peritonitis led to a laparotomy on the third day, although it is recognized this is always a bad time for operation. In the two patients who developed abscesses it is possible that these followed the permeation of organisms through a contused bowel wall.

The results justify the adoption of a conservative management of such patients, especially if seen after twenty-four hours.

In neither of the two abscess cases were there positive indications demanding immediate laparotomy.

We must record the devoted care given at sea to these patients by Surgeon Lieut. J. B. McIntosh, R.N.V.R., and Surgeon Lieut R. Aston, R.N.V.R., and thank them for their accurate records, made under great difficulties.

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## THE RECOGNITION AND FIRST AID TREATMENT OF "GAS CASUALTIES"

In this chapter an attempt is made to indicate and deal with the difficulties of Medical Officers to whom gas casualties are sent for treatment. The proper treatment of such cases demands a correct diagnosis of the condition from which they are suffering. In order to avoid men being sent back to duty when they are in the quiescent period which may follow even severe gassing with a lethal gas such as phosgene, and also to prevent the evacuation as casualties of those suffering merely temporary discomfort from lachrymatory or sensory irritant gases, it is absolutely essential that all Medical Officers should be familiar with the symptomatology of gas poisoning.

It is also of the first importance that, when gas is used by the enemy, the fullest and earliest information possible be given by the military authorities to medical units, not only to facilitate the correct diagnosis of individual cases, but also to permit of arrangements for their reception being made on an adequate scale.

Further, in order that men only temporarily distressed by a harmless gas should not be sent unnecessarily to medical units, it is equally important that all officers commanding troops in the field should be familiar with the various types of war gases.

### History of the Case

The patient will generally be able to give a definite history of exposure to gas and to describe the smell of the gas and his initial and subsequent symptoms.

If the patient is unconscious a history of the man's exposure obtained from others will help in deciding whether his condition is due to gas and which gas is implicated. In both cases the Medical Officer's questions should be directed on the following lines —

- (1) Under what conditions did exposure to the gas take place?  
(e.g. position in the field whether exercising actively or at rest, whether in the open or in a dug out, etc.)
- (2) What did the gas smell like?
- (3) For how long (minutes or hours) was the gas breathed?
- (4) What effects did it produce at the time?
- (5) Did symptoms persist after adjustment of the gas mask?
- (6) What symptoms appeared later?
- (7) What period of time has elapsed since gassing—hours or days?



## *The Recognition and First Aid Treatment of "Gas Casualties"*

The significance of the replies to these questions will now be considered, and the various types of gases will be dealt with in turn.

### **Mustard Gas Vapor: Diagnosis**

The symptoms of a casualty from mustard gas vapor will vary according to the concentration of the gas and the duration of exposure.

The characteristic symptoms are: conjunctivitis, laryngitis, and skin burning, but these only develop after some hours.

Should a respirator have been worn during exposure, reddening and even vesication of the skin in the more sensitive regions may have occurred without damage to the eyes or respiratory tract.

The immediate treatment of such cases is the removal of the clothing which is impregnated with the vapour of mustard gas. Continued wear of such clothing will greatly aggravate the severity of skin burns.

### **Lewisite and Other Arsenical Vesicant Vapors: Diagnosis**

Lewisite vapour will cause marked irritation of the respiratory tract, and personnel so exposed will adjust their respirators before damage to the eyes or lungs can occur. High concentrations will cause skin burning in personnel protected by the respirator. Treatment is on the same lines as for mustard gas.

The clothing of persons exposed to Lewisite vapour will, unlike clothing worn in mustard gas vapour, generally have a strong unpleasant smell. Clothing smelling of Lewisite should be removed as early as possible.

### **Liquid Mustard Gas and Other Vesicant Liquids: Diagnosis**

The Medical Services are not usually responsible for the recognition nor for the treatment of personnel so contaminated until such time as they have sustained skin or eye injuries which require treatment.

Contamination by liquid vesicants may vary greatly in degree, from a few drops, which may readily escape notice until skin burns appear, to a thorough drenching from a successful low-altitude spray attack, or from being in close proximity to the burst of a bomb.

The immediate treatment necessary for such cases of gross contamination should have been carried out in the unit immediately after contamination, viz. removal of the clothing and decontamination of the areas of skin affected.

### **Lung Irritant Gases: Diagnosis**

Cases of all degrees of severity may occur, and sometimes it is not



**gassing** The treatment consists of a brief period of rest coupled with the assurance that recovery will be rapid and complete

### **Carbon Monoxide: Diagnosis**

The recognition by a Medical Officer of cases of carbon monoxide poisoning in war time should not be difficult if he be familiar with the possible sources of such poisoning and if he can obtain a history of the circumstances in which the condition occurred

In the milder cases the symptoms are headache, giddiness, breathlessness on exertion, weakness of the legs and inco-ordination of movement, mental irritability or confusion. In the severer cases unconsciousness will be profound. A blood examination may help to decide the diagnosis

The immediate treatment should be—removal to fresh air, the administration of oxygen containing 5·7 per cent of carbon dioxide (if the apparatus is available), coupled with artificial respiration if the breathing shows signs of failure. Care should be taken to keep the patient at rest and warm, and to prevent him from accidentally injuring himself whilst mentally confused

### **Nitrous Fumes: Diagnosis**

The recognition of cases of poisoning by these gases presents many difficulties in the early stages owing to the insidious nature of the onset. The incomplete detonation of a charge in a mining gallery or the breathing of the vapour arising from the spilling of nitric acid on a wooden floor may evoke a little coughing which soon subsides, hours later, however, œdema of the lungs may follow and prove fatal

The recognition of such potential casualties must to a large extent depend on the history of exposure, when such a history is established, the treatment must, as in the case of phosgene gassing, be largely that of watchful anticipation for a period of at least 24 hours. In the meantime, complete rest is imperative, and if pulmonary œdema should develop its recognition and treatment follow closely the lines already laid down for cases of phosgene gassing

### **Screening Smokes: Diagnosis**

These smokes are harmless in the concentrations which form effective screens, and casualties do not therefore occur except in the case of men who may come in contact with the compounds before they have been dissipated in the form of smoke. The first aid treatment required for such accidents depends on the nature of the chemical employed



### *The Recognition and First Aid Treatment of "Gas Casualties"*

Phosphorus is solid, and burning fragments on the skin or clothing must be put out at once by immersion in water or envelopment in cloths soaked in water. Other smoke producing compounds are generally liquids of a strongly corrosive acid nature. The first aid treatment for personnel splashed by these agents is the same as that required for persons who have been contaminated with any acid, namely, the rapid removal of the soiled clothing and the flooding of contaminated skin areas with water.

For the prevention of accidents to those engaged in handling these compounds the wearing of oilskin clothing and a respirator or goggles is recommended.



APPENDIX I

SUMMARY OF GASES, PROPERTIES, METHODS OF RECOGNITION AND FIRST AID TREATMENT

Type	Properties	Methods of recognition	Effects	First aid treatment
<i>Choking Gases</i> Phosgene (C.G.)	Almost invisible gas. Corrodes metals. Renders less effective. Non-persistent	Smell of musty hay. A trace of phosgene in the air makes smoking unpalatable	Highly lethal effects — cough and lachrymation; pain in chest, dyspnoea; later pulmonary oedema. Effects appear in 0 to 24 hours	Complete rest essential. Warmth.
Chlorine	Greenish coloured gas. Corrodes metals. Repeated exposure rots clothing. Non-persistent	Smell similar to bleaching powder.	Like phosgene but more irritant and less toxic.	Ditto
Diphosgene	Colourless liquid, invisible gas. Semi-persistent.	Resembles phosgene.	Like phosgene.	Ditto.
Chloropicrin (P.S.)	A colourless volatile liquid. Semi-persistent	Pungent odour.	Like phosgene but more irritant and lachrymatory and less toxic, though more toxic than chlorine. Cumulative.	Ditto.
<i>Nasal Irritant Gases</i> Diphenylchlorarsine (D.A.). Diphenylamine chloroarsine (D.M.). Diphenylcyanarsine (D.C.).	Colourless or bright yellow crystals. When heated give off odourless smoke, invisible except near source. Non-persistent.	By onset of effects.	Produce sneezing, burning and aching pain in chest, throat, nose, gums. Later mental depression. First effects 0 to 5 minutes.	On removal to an atmosphere free from the gas recovery is usually rapid without treatment, but effects may increase for the first few minutes in fresh air.



APPENDIX I—continued

SUMMARY OF GASES, PROPERTIES, METHODS OF RECOGNITION AND FIRST AID TREATMENT

The Recognition and First Aid Treatment of "Gas Casualties"

Type	Properties	Methods of recognition	Effects	First aid treatment
<i>Tear Gases</i> Chloroacetophenone (C.A.P.).	Colourless crystals. Invisible in gaseous state. Non-persistent.	Onset of effects: smell of 'Ronnk' or cheap scented soap.	Stinging of eyes. Immediate and profuse lachrymation. Blepharospasm. Skin irritation of exposed areas.	Recovery usually rapid without treatment.
Ethylidooacetate (K.S.K.).	Dark brown liquid. Invisible in gaseous state. Persistent.	Onset of effects; fruity smell.	Ditto. Irritates nasal mucosa but not skin.	Ditto.
Bromobenzylcyanide (B.B.C.).	Pure—yellowish brown crystals. As used—brown liquid. Persistent.	Onset of effects; pungent penetrating smell.	Ditto.	Ditto.
<i>Blister Gases</i> Mustard gas (H.)	On oily liquid varying in colour from dark brown to straw yellow. Soluble in oil, fats and organic solvents. Penetrates rubber, leather, wood, cloth, etc. Very persistent. Neutralized by chlorine (e.g. bleaching powder).	Smells of garlic, horseradish, onions, or mustard.	(i) <i>Vapour effects</i> — <i>Eyes</i> .—Irritation and inflammation with swelling within 24 hours. High concentration causes tears earlier. <i>Skin</i> .—Redness, irritation, blisters. Damp parts specially affected. <i>Respiratory passages</i> .—Aphonía and cough. Later, bronchitis and possibly broncho-pneumonia.  (ii) <i>Liquid effects</i> —irritation of <i>Eyes</i> .—Immediate	1. Remove clothing. 2. Wash patient with soap and water, if available. 3. Wash out eyes repeatedly.  1. <i>Eyes</i> .—Immediate and frequent irrigation of



APPENDIX I—continued  
SUMMARY OF GASES, PROPERTIES, METHODS OF RECOGNITION AND FIRST AID TREATMENT

Type	Properties	Methods of recognition	Effects	First aid treatment
Lewisite	A colourless liquid when pure, brown in the crude state Gives off an invisible gas Is rapidly destroyed by water and any alkali Great power of penetration Very persistent but less so than mustard gas	Smell of geraniums	<p>(1) <i>Vapour</i>—Causes severe irritation to nose Hence respirator will be adjusted immediately so that there will be no permanent effect on eyes, nose or lungs Is less effective on skin than mustard gas vapour</p> <p>(2) <i>Liquid</i>— (a) in eyes, immediate effect and permanent injury</p>	<p>eyes with any available warm water or preferably saline</p> <p>2 <i>Skin</i>—Ointment, A G No 1 or No 2, bleach paste or solvent</p> <p>3 <i>On clothes</i>—Remove clothing apply ointment or bleach paste to affected area of skin Scrub the skin with soap and water or use solvents</p> <p><i>Note</i> Decontaminating materials stated in order of preference, but if skin already reddened solvents are preferable</p> <p>Similar to H except that Ointment A G No 2 must be used in place of No 1 Water more effective with lewisite than with mustard gas Large blisters should be opened antiseptically and drained</p>



SUMMARY OF GASES, PROPERTIES, METHODS OF RECOGNITION AND FIRST AID TREATMENT				
Type	Properties	Methods of recognition	Effects	First aid treatment
Paralyzant Gases Hydrocyanic acid	A colourless volatile liquid. Non-persistent.	Smell of bitter almonds.	(b) On skin; blisters develop more rapidly than with mustard gas.  Small amounts of vapour cause giddiness and headache—larger doses cause unconsciousness and death.	<i>Urgent.</i> —Artificial respiration. Oxygen inhalations, or better oxygen containing 5-7 per cent. carbon dioxide.
Hydrogen sulphide	A colourless gas. Non-persistent.	Smell of bad eggs.	Small doses cause irritation of eyes and nose and bronchitis; large doses cause unconsciousness and death.	<i>Urgent.</i> Ditto.
Aseniumretted hydrogen	A colourless, odourless gas. Non-persistent.	Special test papers.	Weakness, headache, vomiting, haemoglobinuria, jaundice, anaemia.	Require hospital treatment.
Other Gases Carbon monoxide	A colourless, odourless gas. Non-persistent.	Practically no warning before onset of symptoms.	Causes giddiness, muscular weakness, then unconsciousness and death.	<i>Urgent.</i> —Artificial respiration. Oxygen inhalations, or better oxygen containing 5-7 per cent. carbon dioxide.
Nitrous fumes	Reddish brown fumes. Non-persistent.	Pungent smell.	Irritation of nose, throat and lungs; later pulmonary oedema.	Similar to phosgene.

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## THE NUTRITION OF THE SOLDIER

By LIEUTENANT COLONEL MILTON H EPSTEIN  
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While the soldier's official intake is via the army ration, and its discussion would therefore seem to be the logical beginning to any presentation of the subject of military nutrition, it will be omitted here.

Recognizing, then, a larger aspect of the problem of caring for the metabolic and protective needs of the human organism (for it is, of course, clear that the major objective in the army does not differ from that in civil life), it must be said that evidences of dietary deficiencies may occur whenever a pronounced unbalance in the intake has persisted for a considerable time. Though admittedly seemingly impossible of accomplishment (most soldiers think they are being starved unless they are being fed meat and potatoes three times a day), every effort should be made to have them consume a balanced diet. Made up two thirds (by weight) of carbohydrates, one sixth of proteins and one sixth of fats, the first named component should consist largely of the 'protective foods (leafy vegetables, fruits and milk). The importance of bulk must be recognized here. Clear soups, coffee and tea leave practically no residue, eggs, meat, fish and proteins generally, little. Bulk must be supplied through whole grain cereals, fruits, and especially the vegetables that are rich in cellulose.

This is a colitis ridden nation due largely to the fad of eating in their raw state fruits and vegetables that require cooking to make them fit for human consumption. After all, the application of heat to foods represents the most important difference between the eating habits of man and animal. This applies not only to starches, but to many proteins as well. Fish should be thoroughly cooked to guard against worm infestation, pork likewise, to render the trichine organism harmless.

The most effective utilization of the proteins in lamb, however, is obtained when it remains slightly rare, and the same holds true for beef. Soldiers are, as already mentioned, ordinarily great meat eaters. They do not have to be coaxed. But quality as well as quantity is important here, as certain of the essential amino acids are not manufactured synthetically in the body.

Until recently, milk, a food that authorities on nutrition have long recognized as the classic perfection for growing children, was considered to be of doubtful value for adults, repeated tests having shown that only a small per cent of men and women (somewhere around 15) were able to digest it properly and without discomfort. If this is because



the albumen is "buffered" (that is, held away from the digestive juices by lime), the trouble can usually be overcome by drinking the milk sour, or with orange or vegetable juice added, so this objection is not an insurmountable one. But the chief indictment against milk for adult use was its heavy calcium content. It was believed that, by furnishing this element in excess of body requirements, milk was contributing to the incidence of the degenerative diseases of middle age characterized by calcification of tissue. We feel now, however, that this is not a practical danger; milk may well raise sub-normal blood calcium to the normal, but any excess is not stored. If such excess occurs it is due to some organic malfunction in the individual and not to the milk of itself.

As for the fats, there was a time in military history when soldiers were plied with fat foods whenever available and with malice aforethought. The greater length of time required to digest this component kept the soldier from getting hungry again too soon. The undesirability of such delayed emptying has, of course, long since been recognized. In this connection I was interested to note at one of our large new army hospitals recently that the mess provided a 34 per cent fat component, or twice the generally recommended limit. Furthermore, the caloric intake there was about 3,700, which is obviously high for a man at rest.

An average man of moderate activity living in a temperate climate should consume about 2,500 calories per day. Soldiers in the field or doing active outdoor work require from 4,500 to 5,000; carrying a full pack from 6,500 to 8,000. In cold climates this may run up to 9,000 or even 10,000, made up of carbohydrates, proteins and fats in the proportion previously suggested, but keeping in mind that fat is the variable to meet different climatic conditions.

Such menus as I have recently seen used in Southern California provide 4,500 to 5,000 calories per day, but as no provision exists for the appraisal of the caloric value of the spoilage, wastage and food refused by the soldier, we have no accurate figures on actual consumption.

Even though the fact is generally known, I must mention here, as a routine matter, that there are no incompatibles in foods. Allergy or other idiosyncrasy alone accounts for certain individuals being adversely affected after eating certain food combinations. That is because they are allergic to one or more of the ingredients, and not on account of their mixture. Nothing in the recognized literature of modern medicine even suggests that there has even been demonstrated any interaction between foods that makes any food combination harmful, assuming, of



course, that the separate foods themselves are fresh and sound

In recent years there has been an addition to the American dietary which I must mention because of its possible ultimate importance to our country in a military sense, it being already freely utilized in the nutrition of certain foreign armies. This is the soy bean. It may be prepared in many palatable ways, is highly digestible, and is a first class all round food containing 20 per cent fat, 20 per cent carbohydrate and  $36\frac{1}{2}$  per cent protein of a form closely resembling animal protein. First grown commercially in the United States in 1924, it is true that production has only doubled in the intervening 17 years, but it is a foodstuff that has most interesting possibilities.

There is yet another form of 'balance' in the diet that must be mentioned, even though it attracted much more attention a few years ago than now, and that is the relative proportion of acid ash and alkaline ash producing foods in the intake. Seldom does one now hear the once common admonition to eat an orange for every egg and to drink a half a glass of milk for every slice of bread eaten. When I was last abroad, ordinarily cautious European scientists were accepting the conclusions of certain well publicized American enthusiasts in this field without question, because the intervening theory seemed sound. In the field of experimental science, however, and particularly in the biologic division, logic is no substitute for proof. For example, the criticism is often made that the American dietary is too high in its ratio of acid ash producing food concentrates and carbohydrates, and too low in vitamins and bulk. This indictment is undoubtedly deserved, but with reference to the acid ash producing food, it is quite inadequate to submit only the results obtained in experimental animals having a relatively short life span as final proof that the direct causes of many diseases in the human are traceable thereto. I am referring, of course to the diseases encountered in middle life characterized by degeneration of the tissues.

In addition to the three components I have already referred to, the balanced diet must contain the requisite mineral salts and vitamins and enough water for the body metabolism. As for the first named, sufficient quantities of sodium, potassium and magnesium are present in the customary food of the soldier just as they are in the dietary of the civilian and need not ordinarily be given special consideration.

One of the more pleasurable experiences for the nutritionist at army posts in recent years has been to see the great quantity of milk consumed. Obviously this takes care of calcium requirements. Milk should be pasteurized for safety's sake the only nutritional disadvantage being



the destruction of Vitamin C thereby and some diminution in Vitamin B. Milk also contains Vitamins A, D and E, all in only moderate quantities however.

For some reason the soldier dislikes fish, and ordinarily will not eat it. But the meat, eggs, oatmeal and some of the other foods that he likes and which are plentifully included in his customary intake are amply rich in phosphorous and sulphur. Iron deficiency is seldom met with in the common dietary. Wheat germ is the richest known source of the copper necessary for the assimilation of the iron. Copper is also found in appreciable quantities in peas, kidney beans, asparagus and, of course, meat. In endemic colloid goitre areas the lack of iodine in the water and locally raised vegetables is taken care of by the use of iodized salt.

The dangers that are believed to lurk in highly excessive vitamin intake exist, if at all, only in the ingestion of concentrates, and since this is (or should be) purely a therapeutic measure, a consideration of these dangers is outside the scope of this discussion.

With the easy availability, these days, of fresh fruits, vegetables and meats, the military nutritionist should currently have no difficulty in furnishing *in their natural sources, and therefore without danger of* overdosage, adequate amounts of every known essential vitamin, with the possible exception of "D" in climatic conditions that do not permit this vitamin to be synthesized in the body. Administration of fish oils or sufficient egg yolk is not practicable, and consequently irradiation of milk or bread may have to be resorted to in such a case.

To care for metabolic needs, many physicians still fix arbitrarily upon six to eight glasses of water to be drunk daily. This is a bad rule. There is too great a variation in individual requirements. The prescribed quantity may be wholly inadequate in one case and so excessive in another that a completely unnecessary strain is being imposed on heart and kidneys. While appetite is not always a dependable guide to the proper food intake, the tissues' needs for water are, in the normal individual, usually translated into an exactly corresponding thirst, which is, therefore a better guide to quantity in water consumption than is any set amount. Another long standing theory regarding water intake has had to go by the board recently. Exhaustive experiments, scientifically conducted, have shown that, contrary to previous belief, water may be ingested before or during meals without handicapping digestion since, in the former instance, the dilution of the digestive juices does *not* actually delay digestion, and in the latter digestion proceeds and the stomach empties just as rapidly as though the temperature of its



contents had not been temporarily lowered by the cold water intake.

It is exceedingly difficult to *change* the dietary habits of soldiers. Put salads and fruits before them and, even though this be done because the day is sweltering hot, they will leave these foods untasted and fill up later at the post exchange on candy bars and peanuts, ice cream and soda pop. In this way the soldier sometimes eats five or six "meals" a day, which disorganizes the regularity of his bowel movements and, by hastening them, prevents the maximum absorption of nutriment from his food.

I have just commented on the soldier's innate resistance to accepting certain highly desirable foods. In concluding I want to mention the administrative difficulties in even *exposing* him to a proper diet. As a military installation is now conducted, it is, in the last analysis, the mess sergeant who feeds the men. Ordinarily he is himself one of the "meat, gravy and potato" boys, and his interest, and educational background are seldom such as to encourage efforts to train him along nutritional lines. This problem is currently attracting attention in important circles and I hope to see the day when the feeding of the soldier will be strictly in accordance with the nutritional principles laid down by an expert with sufficient military rank to assure his recommendations being carried out.



# The Nutrition of the Soldier

**PROTECTIVE FOODS**  
Content of Calcium, Phosphorus, Iron, and Vitamins A, B<sub>1</sub>, C and D

	Mgm. per oz			International units per oz				Notes
	Ca	P	Fe	A	B <sub>1</sub>	C	D	
<b>Dairy Foods :</b>								
Butter .. ..	4.2	7.0	0.05	226-1,940	—	—	24-113	
Cheese (hard) ..	230	134	0.2	1,354	1	—	—	
.. (soft) ..	205	137	0.2	—	15	0	—	
Eggs (per egg) ..	20	140	1.6	24-1,220	6.5	negligible	23-75	
Milk .. ..	34	27	0.03	17-153	—	—	negligible	
<b>Salad Vegetables :</b>								
Mustard and Cress	19	19	1.28	—	14	—	—	Vitamin C prob-
Radishes .. ..	12	8	0.84	1	0.2-2.0	70-114	—	ably high.
Tomatoes .. ..	4	6	0.12	4,000-10,000	11	74-218	—	
Watercress .. ..	63	15	0.48	—	17	136-431	—	
<b>Green Vegetables :</b>								
Cabbage .. ..	13	7	0.13	255	7	113-807	—	Vitamin A and C
Sprouts .. ..	8	13	0.18	—	17	414-818	—	figures are for
Spinach .. ..	[169]	20	(1-13)	746-1,840	5.7-80	34-703	—	raw vegetable.
Turnip tops (boiled)	28	13	0.37	—	3	—	—	Vitamin C figure
Carrots .. ..	10	5	0.11	567-2,740	—	—	—	for raw vege-
<b>Summer Fruits :</b>								table.
Currants (black) ..	17	12	0.36	85-140	0.6	772-1,948	—	
.. (red) ..	10	8	0.35	—	3-6	283	—	
Gooseberries ..	5	5	0.10	—	—	156-266	—	When canned
Loganberries ..	10	7	0.39	—	7-10	116-274	—	about half the
Raspberries ..	12	8	0.34	—	traces	173	—	vitamin C is
Strawberries ..	6	7	0.20	—	—	201-439	—	retained
<b>Foreign Fruits :</b>								
Banana .. ..	1.9	8.0	0.12	71-85	14	67-84	—	Pulp of large
Grape-fruit ..	5	4	0.07	—	11	147-269	—	bananas weighs
Lemon juice (fresh)	8	10	0.14	—	11	143-404	—	3 oz.
Orange juice (fresh)	12	7	0.09	85-113	—	185-504	—	
<b>Fat Fish :</b>								
Bloaters .. ..	23	85	0.41	—	—	—	—	Probably useful
Herrings .. ..	16	84	0.52	136-182	0	—	234	for vitamins A
Kippers .. ..	8	54	0.18	—	—	—	—	and D
Salmon (fresh) ..	0	62	0.16	—	—	—	—	
.. (tinned) ..	18	79	0.36	0-23	—	—	57-237	
Sardines .. ..	110	194	1.14	637-7,650	—	—	227	Probably useful
Whitebait .. ..	244	243	1.44	—	—	—	—	for vitamins A
<b>Sundries :</b>								and D.
Bacon .. ..	2	44	0.26	Probably 0	79-136	Probably 0	0	
Ham .. ..	5	70	0.74	234,000 to	62	187	0	
Liver .. ..	9	570	5.20	432,000	43	—	—	
Wholemeal bread ..	9	56	0.70	29-129	35	Probably 0	Probably 0	

Amounts needed per day—

Calcium—600-700 mgm. for an adult male and non-pregnant adult female  
 1,000-1,600 mgm. or more for a pregnant or nursing female  
 1,000 mgm. for a child up to 14.  
 1,600 mgm. for an adolescent.  
 Iron—10-15 mgm. for almost anyone at any age. Females after puberty need at least as much as males.  
 A—5,000 International Units B<sub>1</sub>—300-500 International Units.  
 C—600 " " D—250 " "

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# LIQUEFACTION OF SOLID FOODSTUFFS FOR DIETS

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The feeding of sick and convalescent patients adequately and effectively has long been a problem for the physician. The weakened digestive functions of these patients demand a liquid or soft diet and this necessarily limits the number of foods available to them. Essentially the difficulties have centered around the problem of breaking down complicated carbohydrate and protein molecules, so that these foods become more readily absorbed and assimilated. The patient is too weak to exert the necessary energy to masticate solid or semi solid foods properly and besides, his depleted enzymes cannot be depended upon to do their part in the breakdown function of the digestive process<sup>1</sup>. The patient perforce is given a routine diet which soon becomes monotonous and is necessarily lacking in some essential elements.

It is evident that if some mechanical aid was enlisted to get the food into a more assimilable form before it is ingested, the problem would be nearer solution. With this end in view, we have been using a colloid mill at the Fort Totten Station Hospital for the past six months with very gratifying results. This machine has facilitated the preparation of special diets and required foods for patients. Also, specific problems of diet have been solved largely because we have had at our disposal the means of changing highly nutritious food, heretofore contraindicated because of its solid state, into liquid form.

The use of a colloid mill in medicine is not new—it has been an important factor in the manufacture of intravenous injection materials, reduction of glands for serums, premastication of vegetables for infant feeding and the manufacture of pharmaceuticals of all kinds.

The colloid mill we have been using is of simple design,\* having only one moving part. A separate grinder is used as a preliminary step to premix the solid food and get it into a somewhat macerated state. A little water is added to the mass and it is then introduced into the hopper of the mill from whence it passes into a chamber, where the material is set into rapid motion. A built in centrifugal pump applies pressure on the material as soon as it is introduced. The mill then subjects it to three distinct actions: first, the top turbine whirls it violently and the high velocity impact breaks up the liquid into minute globules, secondly, the material is mechanically sheared by the teeth in the rotor and stator, and third, it is hydraulically sheared by the final smooth

\* Eppembach Colloid Mill



surfaces of the rotor and stator.

As the material is emulsified, it passes into a metal hose and is recirculated through the mill, thus gradually reducing the particles to smaller and smaller size. In addition, the particle size is influenced by the size of the gap, which is regulated by a micrometer adjustment device. The grinding surfaces are surrounded by temperature chambers through which water flows, so that the material may be processed and discharged cool. For example, a heat sensitive material such as whites of eggs may be processed without coagulation. It might be added that there is no incorporation of air in the product and no hazard of contamination due to contact metals (stainless steel is used). The machine is self-cleaning, comparatively noiseless and no technical skill is required to operate it.

#### **Advantages**

Among the numerous favorable effects resulting from the use of the colloid mill, the following are especially important:

1. There is earlier absorption of food.
2. The period of convalescence is shortened.
3. Mineral substances are in greater solution, and thus their speed of absorption from the digestive canal is increased.
4. Vitamin content of food is more available because of the breakdown of complicated molecular structures. Vitamins are known to lodge in the fibrous elements of a food,<sup>2</sup> and these are retained when the colloid mill is used. The latter device is therefore superior to juice extracting machines also used in the preparation of special diets.

The inclusion of sufficient vitamin content in military rations in general is a very important consideration. While it is not within the scope of this article to discuss the vitamin alphabet fully, the following should be mentioned. Vision improves materially when large doses of Vitamin A are administered. It is therefore highly important in the dietary of soldiers, particularly aviators. As a matter of fact, avitaminosis of this vitamin in human beings is tested by the eyes' ability to see in the dark. Vitamin A also plays an important role in the treatment of generalized infections, skin diseases, wounds, hyperthyroidism, etc.<sup>3</sup> Eddy and Dalldorf<sup>4</sup> found that lack of Vitamin A also frequently affects some internal organs: the bronchi, pelvis of the kidney, pancreas and prostate.

Vitamin B<sub>1</sub> seems to postpone fatigue and has a favorable effect on the nervous system. Also, its role in the normal functioning of the gastrointestinal, cardio-vascular and hematopoietic systems is well known.<sup>5</sup> It is interesting to note that Vitamin B<sub>1</sub> is considered a strategic war-time product.



5 Certain foods require lengthy cooking, but by using the colloid mill to mechanically grind them first, the cooking time is reduced. Prolonged cooking destroys some of the vitamins and preliminary use of the colloid mill here is self evident.

6 For patients whose alimentary canal is in an inflamed or irritable state roughage in the form of harsh fibered vegetables, skins of fruits, etc. is to be avoided and the colloid mill is almost indispensable in the preparation of these diets.

7 A greater variety of foods can now be included in the special diets of patients.

8 The colloid mill enables the preparation of natural foods with a minimum destruction of enzymes and minerals. The food is freshly prepared and served immediately, thus avoiding the evils of processing and canning. It is well known that preservatives in canned goods and sometimes the contact metals destroy the enzymes and mineral content.<sup>6</sup>

9 It has been gratifying to note the lowered incidence of digestive disturbances at the hospital with the use of the colloid mill.

10 The weight and strength of the patient are maintained, and in many instances an otherwise bedridden patient may remain ambulatory.

### Therapeutic Implications

The present conception of treatment in high fever cases, is primarily not to cut down on caloric intake, fluid intake and proteins in the diet. Most infectious fevers are characterized by a toxic destruction of body protein<sup>6</sup> and this must be replaced. Pronounced differences exist in the composition of proteins from various food sources and a practical problem in protein nutrition is the provision of foodstuffs whose proteins furnish amino acids needed by the body and in the requisite amounts.<sup>7</sup> Since most of the desirable proteins are solid or semi solid foods, solution of this problem has been difficult. A very sick patient lacks the desire for food and has no inclination to masticate even the foods included in the soft diet. But with the possibility of liquefying foods, we have been able to sustain the patient's energy and provide the necessary nutrition with a minimum amount of effort on his part. He can get adequate food intake by simply sipping through a straw or drinking tube a completely balanced meal.

This method of nutrition lends itself particularly well when fractures of the head, neck or jaw and conditions about the mouth are involved. In these cases solid foods cannot be taken and at the same time a high caloric diet is necessary. Also, the healing of fractures is hastened by a



diet high in calcium and phosphates<sup>7</sup>—the colloid mill facilitating the preparation of both.

A colloid mill is indispensable in the proper feeding of the *moderate and severe anemias*, requiring liver administration. We have been able to supply raw whole liver to these patients in assimilable form. A certain loss occurs in cooking liver, as the active material is water soluble and some may escape in the juice.<sup>7</sup>

Likewise, in cases where *nerve* regeneration is a desirable factor, sweetbreads and pancreas (cephalin) have been given the patient in emulsified form with good results. There is some evidence that liver and kidney tissue are equally effective in these cases.<sup>7</sup>

### **Possibilities of the Colloid Mill**

Eye appeal is not a negligible consideration in connection with food preparation. Steaks and fish could be ground up in a mill and then mixed with a material having cohesive properties, such as casein or egg white (depending on the food), and thus the food could be reconstructed to resemble its original form.

Whole wheat flour is superior to white, but is very difficult to keep as it is subject to mold, moisture conditions, etc. However, wheat in the proper casing provided by nature can be kept for hundreds of years. In the future armies may be able to carry the whole wheat grain with them, grinding it in a portable mill just before it is to be made into bread. It is known that Caesar who pushed his armies far, intuitively applied the principles of natural foods to his soldiers. The worn down teeth of exhumed skeletons found in the regions of his battles, show that Caesar's men were chewing whole wheat kernels and other roughage. Perhaps this was the secret of Caesar's success.

The colloid mill may be used to make extracts to flavor other foods. We have been using them at the hospital to make nourishing drinks of all kinds. We have also incorporated them into breadstuffs, thereby adding to the nutriments of the latter.

The ramifications of this phase of the subject are unlimited and should serve as a basis of further study for the earnest student of dietetics.

### **Conclusions**

1. A colloid mill is of inestimable help in the preparation of special diets for sick and convalescent patients. It makes foods more assimilable and a more varied dietary possible.
2. Therapeutic feeding in various conditions is facilitated.
3. The role of the colloid mill in future dietetic research should be an important one.



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## ALLERGY IN MILITARY MEDICINE

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In 1906 Von Pirquet,<sup>1</sup> a European physician, coined a new word, "Allergy," from the two Greek words—*allos* (altered) and *ergia* (reactivity) which means literally "changed or altered reactivity"<sup>2</sup> and which he defined as "changed reaction capacity which the human or animal organism gains through recovery from disease or through treatment with foreign substances."<sup>2</sup> It has been used synonymously with hypersensitiveness and idiosyncrasy. "Allergen" is the term used for a foreign substance which is capable of exciting an allergic reaction.<sup>3</sup>

It has only been during the past ten years that the term, allergy has come into common usage within the medical profession as well as the laity. At the present time, however, the term is heard everywhere, as it has become a household word and is even used in cartoons, newspaper columns and on the motion picture screen.

### Allergic Manifestations

Most people think only of hay fever and bronchial asthma when allergy is mentioned. However, those who have made a special study of the various allergic manifestations are more and more realizing that there is hardly any human disease or condition which may not have an allergic factor involved. Practically any part of the body may be affected. Each day our knowledge of allergy is increasing.

The etiology of allergy may be classified as follows: pollen allergy, food allergy, serum allergy, drug allergy, bacterial allergy, and physical allergy. Clinically, allergy may be manifested as asthma, hay fever, allergic rhinitis, gastro-intestinal allergy, migraine, and the various allergic dermatoses such as urticaria, angio-neurotic edema, allergic eczema or atopic dermatitis and contact dermatitis.

### Inheritance

It is generally agreed that allergy is a hereditary disease in that an individual inherits a predisposition to allergy or an allergic tendency which may or may not be manifested at some later date. In 1916 Cooke and Vander Veer<sup>4</sup> showed that allergy was inherited. This observation was later confirmed in 1924 by Spaine and Cooke<sup>5</sup> and "that this tendency seemed to be transmitted as a Mendelian dominant characteristic."<sup>6</sup> It was found that when both parents are sensitive 75 to 100 per cent



of the offspring will probably be allergic and when only one parent is sensitive 50 to 75 per cent of the offspring will probably be allergic and when neither is sensitive probably 0 to 10 per cent will be allergic. It was also discovered that the age of onset of the allergic condition is definitely dependent upon the degree of inheritance. Thus the greater the inheritance the earlier the probable onset.

### **Incidence**

In order to show the connection and importance of allergy in military medicine it is necessary to show the incidence of allergy. Since allergy has been recognized as a disease entity only during the past few years it is obviously difficult to arrive at accurate statistics prior to the time it was recognized. This was especially true during the World War.

Vaughan<sup>8</sup> has compiled rather complete statistics on incidence as follows. In 1916 Scheppegetrell<sup>9</sup> of New Orleans sent a questionnaire to Louisiana physicians and concluded that about 1 per cent of the general population suffer from hay fever.

In 1924 Spain and Cooke<sup>10</sup> in a survey of 506 medical students, nurses and patients concluded that 3.5 per cent of the population are subject to hay fever or asthma. They estimated the total allergics at about 7 per cent.

In 1930 Piness and Miller<sup>11</sup> made a survey on the West Coast of two mining communities and in a town of 3000 population found 4.4 per cent had hay fever while in a second town of 1000 population about 3 per cent had hay fever. They found 21.6 per cent of hay fever sufferers also had asthma.

In 1931 Rowe<sup>12</sup> made a survey of 400 university students and nurses. Forty-three per cent gave a family history of allergy, 35 per cent gave a personal history of allergy and 31 per cent suspected foods as a possible cause of symptoms.

In 1934 Vaughan<sup>13</sup> made a survey of an entire community in Clover, Virginia, of 508 people. He found 10 per cent were frankly major allergics and the second group of minor allergics were 50 per cent, or a total of 60 per cent of the entire population were allergics. The forms of allergy represented in this group were as follows:



## *Allergy in Military Medicine*

**TABLE I**

**Distribution of Symptoms Among Major Allergies in a Community of 508 Persons<sup>14</sup>**

Symptoms	Cases	Per Cent of Allergies	Per Cent of Population
Hay fever .....	27	49	5.3
Urticaria .....	25	45	4.9
Gastrointestinal .....	22	40	4.3
Asthma .....	17	31	3.3
Migraine .....	16	29	3.1
Vasomotor rhinitis .....	15	27	2.9
Eczema .....	3	5	0.6
Angioneurotic edema .....	2	4	0.4

In 1934 Jimenez<sup>15</sup> at the Health Service Unit of the University of Michigan, upon the examination of 6,935 individuals, concluded that about 35 per cent of men and women students are definitely allergic and another 20 per cent are potential allergics and that "more than half (54 per cent) of men and women college students should receive a complete sensitization study."

In 1937 Pipes<sup>16</sup> made a careful survey of 700 individuals, residents in and about Jackson, Louisiana, and summer students in the State University at Baton Rouge, and found that major allergics were 13.6 per cent and minor allergics 35.8 per cent, making a total of approximately 50 per cent. Of these, 8 per cent suffered from hay fever and were major allergics. These figures would indicate that Scheppegegrell's former estimate of 1 per cent for hay fever, based on a questionnaire sent to physicians was possibly unreliable, due to the disease not being recognized as such in 1916.

In 1926 Hoffman<sup>17</sup> on the basis of a study of insurance statistics, estimated that there are about 500,000 cases of asthma per year in the United States or slightly under one case in 200 population and that there are 13,000,000 work days lost per year on account of asthma.

In a communication from the Surgeon General's Office<sup>18</sup> to the writer, the following statistics are given:

Total number of officers and enlisted men in service during the World War .....	4,129,479
Total number of hay fever cases reported.....	192
Total number of cases of asthma reported.....	7,924

Among defects found in drafted men in the World War, 6,729 cases of asthma were reported at a rate of 4.41 per 1000 and 39 cases of hay fever at a rate of .03 per 1000.<sup>19</sup>



When compared with more recent statistics it is very evident that these figures showing the number of cases of hay fever and asthma in the World War are incomplete

In 1935 Vaughan<sup>20</sup> reports that 12 per cent of the entire World War veterans receiving disability compensation were asthmatics. Of these 4,644 veterans, 62 per cent were more than 50 per cent disabled and 29 per cent were totally disabled, 86 per cent had established service connection for their asthma. The annual cost of compensation for this group was \$4,874,204.

It would seem that on the basis of the above figures, allergy must be given an important place in military medicine. During the World War allergy was not recognized as a disease. Therefore, we have only incomplete statistics on hay fever and bronchial asthma to say nothing of all the other allergic manifestations which were not recognized. Thus it is evident that allergy is of importance in military medicine and should be dealt with accordingly by the Army's making complete plans for its diagnosis and treatment on a large scale.

The results to be obtained with the proper treatment of allergy offer a higher percentage of success than probably any other disease or condition in medicine.<sup>21</sup> It has been estimated that from 80 to 95 per cent of those treated will either be relieved of their symptoms or greatly improved.<sup>22</sup>

Since allergy is an important factor in military medicine and since the prognosis, after proper treatment is so good, it is logical that the Medical Department of the Army should provide a suitable organization to properly diagnose and treat allergy in all its forms.

### **Policy in Peace**

The policy of the Medical Department of the United States Army at the present time, as outlined in Army Regulations 40-105<sup>23</sup> is to reject those applying for entrance into the Army who have "eczema of long standing or which is rebellious to treatment, acne upon face or neck which is so pronounced as to amount to positive deformity," paragraph 31-34. "Nasal obstruction due to septal deviation, hypertrophic rhinitis, or other causes if sufficient to produce mouth breathing, acute or chronic inflammation of accessory sinuses of the nose or *hay fever*," paragraph 40-43, "Chronic bronchitis, chronic pneumonia, pulmonary emphysema, asthma or bronchiectasis," paragraphs 58-61.

According to a communication from the Surgeon General's Office,<sup>24</sup> "Hay fever and asthma constitute defects which unconditionally disqualify an applicant for admission to the regular Army." Under the



## *Allergy in Military Medicine*

existing policy, the Medical Department of the Army during peace time will have its allergy problem greatly reduced if the examining medical officers are careful in determining all obvious and potential hay fever and asthma cases and rejecting them. According to Vaughan's survey<sup>21</sup> hay fever cases were 5.3 per cent and asthma 3.3 per cent of the population of the community studied. Therefore, if we exclude them in peace time upon examination for entrance to the service we shall have eliminated about 8.6 per cent of the most troublesome allergics but we shall still have all the other forms of allergy admitted to the service.

In the Annual Report of the Surgeon General of the United States Army 1939<sup>20</sup> for the fiscal year ending June 30, 1939 the following statistics are given for the calendar year of 1938.

TABLE 2  
Statistics on Asthma in United States Army in 1939

Total officers and enlisted men .....	182,815
Total number hospital admissions for asthma.....	238
Number per thousand of asthma cases admitted to hospital.....	1.3
Total number of officers and enlisted men discharged for disability due to diseases .....	2,025
Total number of officers and enlisted men discharged for disability due to asthma .....	47
Total number of officers and enlisted men invalided home from overseas stations because of asthma .....	21

TABLE 3  
Disposition of Asthmatics Invalided Home from Overseas Stations

Discharged for disability .....	16
Duty and others .....	3
Treatment continued into 1939 .....	2

In The Surgeon General's Report<sup>22</sup> no classification is given for any other allergic conditions except asthma. Therefore, we have used the above figures to show the prevalence of asthma in the Army of the United States during peace time in spite of the fact that Army Regulations 40-105<sup>23</sup> require that all officers and enlisted men who have asthma be rejected upon their entrance physical examination.

Since the above figures include only those whose asthma was sufficiently severe to require hospitalization, it will be realized there are undoubtedly many more cases of asthma in the Army at the present time than the above figures would indicate. When it is further realized that no statistics are available on the number of cases of hay fever, allergic rhinitis, urticaria, allergic dermatitis, migraine or gastrointestinal



allergy in the Army for the period under consideration, these figures are, therefore, very incomplete as pertains to allergic conditions.

From discussion and statistics previously given, it seems that a fair percentage of the officers and men admitted to the Army in peace time will not show their allergy sufficiently at the time of their entrance physical examination to be rejected. Besides many of them will develop an allergy some time after admission to the service, as has been shown, in the Surgeon General's report for 1939.<sup>29</sup> It has been the observation of the writer during his contact with the Army over a period of many years and in several Army posts that there are quite a number of men in the service who have hay fever, asthma, and other forms of allergy.

If the statistics previously quoted here are correct, that approximately 5 per thousand soldiers or 0.5 per cent have asthma, and if the other forms of allergy are included and we accept the figure that about 10 per cent of the general population are major allergics and require treatment and that 50 per cent are minor allergics and have an allergic manifestation in some form which may become progressively worse and finally reach the point where treatment is required, it is seen that the subject of allergy is of great importance to the Medical Department of the Army both in peace and war.

One of the greatest difficulties at the present time in the control of allergy in private practice is the lack of recognition of allergic conditions by the medical profession. Many allergics are repeatedly operated upon by ear, nose and throat specialists for nasal polyps, allergic rhinitis and nasal obstruction and congestions due entirely to allergy. Allergic dermatitis is treated by dermatologists with lotions, ointments, quartz lights and X ray etc., instead of proper allergy treatment. Gastrointestinal allergy is often mistaken for appendicitis, cholecystitis and peptic ulcers and unfortunately too often unnecessary major surgery is performed. Some physicians, if they suspect allergy, are misled by false negative skin tests when using only a few suspected allergens and not making a thorough and complete diagnostic study of all the possible factors.

Since proper allergy diagnosis and treatment requires special training, it is recommended that the present policy of the Medical Department of selecting a sufficient number of medical officers on the basis of their qualifications as possible allergists, be continued. The officers selected are detailed to attend special post graduate courses on allergy which are given in several of the larger medical centers and post graduate schools. The type of medical officer selected should be one who has had a good ground work of general medicine and who has ability as a diagnostician.



internist and rhinologist, and especially one who has a "Sherlock Holmes" type of investigative mind. In other words, he should be a medical detective who is willing and anxious to run down every possible clue and be patient and persevering while he is determining any and all possible factors in every case.

If it has not already been done, it would seem practical to detail at least one medical officer who has been trained as an allergist to each Corps Area, General Hospital or other major medical installation. His duties would be to supervise the diagnosis and treatment of all allergy work in his area. He could also be used in a consultant capacity. Depending on the distribution of Army personnel, the geography of the Corps Area and medical facilities available, this officer would train other medical officers in the recognition, correct diagnosis and treatment of allergy. Clinical laboratory facilities should be provided for the routine examination of all suspected allergics for eosinophiles in the blood, sputum and nasal smear.

At the present time allergic conditions are being diagnosed and treated in the General Hospitals of the United States Army as outlined in a communication to the writer from the Commanding Officer of the Letterman General Hospital at the Presidio of San Francisco, as follows:<sup>30</sup> "Patients admitted to this hospital for allergic conditions, after having a detailed history taken, are given a complete medical survey with special reference to foci of infection in the nasal accessory sinuses, tonsils, teeth and gastro-intestinal tract. They then receive sensitization tests by the intradermal method, using such allergens as appear to be indicated. These allergens are supplied by the Army Medical School. Where food sensitivity is suspected the foregoing measures are frequently supplemented by the use of test diets, ordinarily using the method outlined by Alvarez, though from time to time Rowe's diets are employed. The hospital has a room equipped with an air filtration system and allergen proof mattresses and pillow covers."

If an allergy diagnostic study is to be made of each case it is necessary to provide a complete set of diagnostic allergens. In private practice the specific allergens in the set vary with the botanical flora in the particular geographic area where the tests are being made.

In the appendix are charts, No. 1, No. 2, No. 3, No. 4, No. 5, No. 6, showing a form for an allergy history blank and a suggested list of diagnostic allergens used by the writer in his private practice and allergy clinics.

It is generally agreed that the routine manner of skin testing is to place the scratch tests on first. The area used for testing may be arms or



back or both. The writer has found that the back is the best and most sensitive area for testing. In most cases 100 scratch tests may be applied at one time if the back is used. This number may be applied daily until the testing is completed. If patients are very sensitive the number may be reduced accordingly. Twenty minutes after the tests are applied they may be read making the proper entries as to negative slight doubtful or positive 1 2 3 4 positive depending upon the size of the wheal pseudopodia and erythema. These may be measured with a millimeter rule and recorded.

The usual procedure is to test only with the intradermal tests those allergens which have given negative or doubtful reactions on the scratch tests. The intradermal tests are more accurate than the scratch tests but are also more likely to cause a severe general reaction unless caution is exercised in their application. In testing large numbers of men in the Army it would seem more practical to use only the scratch test.

In each Corps Area or General Hospital a laboratory technician can be trained to prepare pollen treatment extracts for each individual depending on the results of the skin tests. The writer has found in his practice that the best results are obtained in selecting not to exceed 10 pollens for the treatment. These may be selected according to the relative sensitivity shown by the individual tests and the prevalence of the specific pollens and botanical family groups in that geographical area. They are then made into a pollen treatment extract with a 50 per cent glycerine solution as a preservative and furnished in 5 cc bottles of 1 100 000 1 10 000 1 1000 and 1 100 dilutions. House dust or other inhalants can be furnished in stock solutions of 20 cc bottles of 1 10 000 1 1000 1 100 1 50 and 1 10 dilutions. The pollen and inhalant treatments are usually combined into one syringe at the time of injection. The beginning dose of pollen treatment in most cases is from 0.02 cc to 0.05 cc of the 1 100 000 dilution. If the patient is extremely sensitive or inclined to get a general reaction epinephrine 0.2 to 0.5 cc may be included in the dose in the same syringe being added last. The injections are usually given twice weekly. The intervals between doses may be increased later. In all cases a minimum of at least 20 injections and preferably more which are given in progressively larger doses of the different dilutions must be given. A chart of suggested dosage for an 8 pollen treatment appears in the appendix as Chart No. 7. A suggested dosage chart for house dust is given as Chart No. 8.

#### **Policy in War**

The Surgeon General's Office advised the writer in a personal com



munication<sup>31</sup> that "Under the Selective Service Act draftees with hay fever will be unconditionally accepted for service. Individuals with asthma will be accepted for limited service provided they are not incapacitated thereby for their normal civil occupations. Asthma constitutes a rejectionable defect if associated with chronic bronchitis and emphysema except as provided above."

In case of war the Surgeon General's Office further states<sup>32</sup> that "Mobilization Regulations provide that any special examinations required to further investigate the physical condition of a draftee may and shall be done and that such surveys may be conducted at local community hospitals and medical installations."

If these statistics showing that 10 per cent of the general population are major allergics are correct, the same figure should be applicable to the age group of the draftees in case of war. Then, for an army of 4,000,000 men we can expect that about 400,000 of those drafted will be major allergics.

Since it has been stated by the Surgeon General's Office<sup>33</sup> that these men will be accepted under the mobilization plans, it is easily seen that a well planned program must be developed to give this large number of men proper allergy treatment and supervision to make them assets and not liabilities to the Army.

In each Corps Area, large mobilization center and each training camp or cantonment, a plan should be formulated to place a trained allergist and his staff in charge of the routine diagnosis, treatment and supervision of the large number of men who will be found to be major allergics. A pollen or botanical survey should be made in each Corps Area to determine the pollen diagnostic allergens that will be required. A history sheet covering the necessary questions pertaining to allergy can be made a supplementary part of the regular physical examination form. All draftees who are recognized or suspected allergics will be placed under the supervision of the Corps Area Allergist. If there are several large cantonments or training camps in the same Corps Area it may be found to be more practical to have a plan for treating these allergics in each camp with a trained staff. The diagnosis, treatment and supervision of these men can be carried out by an allergist in such a way that it will not interfere with their military training or routine duties. As rapidly as possible all these men would be given the diagnostic skin tests to determine to just what allergens they were sensitive. This would be done before they were assigned to any branch of the service or to any routine duties. For instance, if a man was found sensitive or allergic to a horse dander, he would not be assigned to the Cavalry; if to wool,



leather or feather pillows, etc., he would not be assigned to the Quarter masters Department, if allergic to certain foods and especially cotton seed oil (used in practically all commercial shortenings) he would not be assigned to cooking mess or commissary work. If he were found hypersensitive to certain chemicals used in gas warfare he would not be assigned to the Chemical Warfare Service.

A special group of barracks or tents would be used by these men where feather pillows, Kapok mattresses, woolen blankets or other things to which they were allergic would not be used. As so many allergies are sensitive to house dust, special provision could be made in these barracks to eliminate much of this dust. An air conditioned, pollen free room could be provided for those requiring it. Those who had a physical allergy to heat cold or sunshine would be desensitized by proper supervision of hot and cold shower baths and exposure to sun and so forth. Inasmuch as most allergies are sensitive to pollens or have a pollinosis, during the time these men were in this special camp they would be desensitized to pollens by injection of pollen extracts two or three times weekly and also desensitized to inhalants. They would eat in special mess halls where the mess would be supervised by the allergist. Since elimination of offending food allergens is the best method of treating food allergy, the mess would be planned to eliminate as many as possible of the common food allergens, and where necessary, special diets could be provided for individuals. Each allergic would be provided with a diet list of just what he was permitted to eat and what was prohibited. Penalties would be provided for those who did not follow their prescribed diet lists. In some cases it might be necessary to provide supplemental vitamin or mineral therapy in addition to the other special mess for individuals who would develop an avitaminosis or malnutrition from the elimination of offending food allergens. The amount of exercise, military drill or other routine duties in which this special group would be permitted to participate would be determined by the allergist in charge. In so far as possible this group would be required to carry on all the regular duties required of all other men in camp. This group need not be considered a hospitalized group but merely a group requiring special supervision while carrying on their military training.

If an intensive program of pollen and inhalant desensitization and food allergen elimination were carried out on this group it is probable that within three to six months most of these men would be ready for practically any military duties. There will be a certain percentage who will probably have to be treated for a whole year and a few who may have to be treated a longer period of time. Some of them will have



to be under treatment and supervision during the entire period of the war. In this case it *might* be decided to discharge these men for physical disability. But this number would be comparatively small.

### **The Results of Treatment**

In 1932 Vaughan<sup>31</sup> reported that 95 per cent of his hay fever patients obtained good results with perennial therapy.

In 1934 Unger and Moore<sup>35</sup> reported good results in 83 to 85 per cent of patients. Phillips<sup>36</sup> gave 91 per cent satisfactory results with intradermal therapy. In 1930 Markow and Spain<sup>37</sup> successfully treated 75 per cent with an additional 15 per cent fair results and failures in 10 per cent. In 1935 Walker<sup>38</sup> reported 98 per cent of his patients greatly improved. In 1936 Hansel<sup>39</sup> reported that complete or satisfactory relief was produced in 75 to 90 per cent of his cases. In 1933 Vaughan<sup>40</sup> prepared a chart on the results of the allergic treatment of asthma and showed that Rowe in 110 cases of asthma obtained a cure in 68.3 per cent and good results in an additional 22.7 per cent or a total of 91 per cent. In the same chart Vaughan<sup>41</sup> showed that Alexander and Zeek treated 69 uncomplicated cases of asthma and obtained 90 per cent either cured or improved and Rackemann in 425 cases produced 25 per cent cures, and 57 per cent improved, or a total of 82 per cent. The writer from his experience in several allergy clinics and a private practice limited to allergy has found that more than 90 per cent of his patients are satisfactorily improved.

The above statistics, based on the experience of a number of allergists as well as the writer's own practice, showing that 80 to 95 per cent of those who remain under allergy treatment and cooperate properly are either cleared up or greatly improved, indicate that the effort required to treat these cases in the Army should be well worth while. The results likely to be obtained in the Army where much closer supervision of the patient can be maintained should be even more successful than in private practice.

### **Summary**

1. It has been shown by surveys that approximately 10 per cent of the general population are major allergics.
2. In a war time army of 4,000,000 men we can expect that about 400,000 will be major allergics.
3. The policy of the Medical Department during war time will be to accept hay fever and asthma cases although during peace time they are rejected.



### *War Medicine*

4 It is recommended that trained allergists in both the Regular Army Medical Corps and Medical Reserve be selected now to fill key positions in the mobilization plan

5 A plan is suggested which may be expanded to meet the situation in war time to have trained allergists treat these allergics in each camp concurrently with their military training

6 Since statistics show that 80 to 95 per cent of allergics who are properly treated are either cleared up or greatly improved it seems evident that the results of treatment of allergics would justify the development of the above outlined program within the Medical Department of the United States Army



# Allergy in Military Medicine

<sup>21</sup> War Department, Surgeon General's Office, Washington, D C Apr 19, 1940, letter from.

<sup>22</sup> *Ibid.*

<sup>23</sup> *Ibid.*

<sup>24</sup> Rowe, *op. cit.* p. 259.

<sup>25</sup> *Ibid.*

<sup>26</sup> *Ibid.*

<sup>27</sup> *Ibid.*

<sup>28</sup> *Ibid.*

<sup>29</sup> Hansel, *op. cit.* p. 630.

<sup>30</sup> Warren T. Vaughan, "Some Rhinologic Aspects of Allergy," *Journal of Allergy* 4:127, 1933.

<sup>31</sup> *Ibid.*

## CHART 1

	Date.....
Name.....	Address.....
Age.....	Race..... S.W.M..... Civil Occupation.....
<b>ALLERGIC HISTORY</b>	
Previous Occupations.....	Birthplace.....
	Other Residences.....
Primary symptoms causing most distress.....	
Secondary symptoms:	
1. Ocular..... 2. Chest..... 3. Nasal..... 4. Skin.....	
Present attacks or symptoms began.....	
and ended (if so).....	
Time of worst attacks: Seasonal..... Perennial.....	
Day ..... Night.... Morning..... Etc.....	
Food idiosyncrasies .....	
Drug and other idiosyncrasies.....	
Hereditary history of allergic conditions.....	
Other allergic manifestations (present and past); as, hay fever, asthma, allergic rhinitis, gastro-intestinal disorders, migraine, hives, urticaria, angioneurotic edema, etc. ....	
Other illnesses or operations and their duration.....	
Do you suspect any food, animal dander, pollen, or other inhalant as being a cause? .....	
Do you have any trouble while in mountains, horseback riding, at beach, on desert, in woods, cleaning house, mowing lawn, in your bed, lying down, around flowers, around trees, grasses or weeds? .....	
Laboratory reports: .....	
Tentative diagnosis .....	
Final diagnosis .....	
Additional history and remarks.....	
	.....Corps
	Medical Officer



# War Medicine

## CHART 2

### POLLENS

Row 1

#### Trees

Acacia  
Ash  
Box Elder  
Black Walnut  
Coast Live Oak  
Cottonseed  
Elm  
English Walnut  
Eucalyptus  
Fremont Cottonwood

Row 4

#### Grasses

Crab Grass  
Darnell Grass  
Giant Rye Grass  
Italian Rye Grass  
Johnson Grass  
Kentucky Blue Grass  
Koeler's Grass  
Meadow Fescue  
Orchard Grass  
Perennial Rye Grass

#### Weeds

Row 1

Allscale  
Beach Bur  
Bractscale  
Careless Weed  
Costal Sage  
Cocklebur  
Common Sagebrush  
Dandelion  
English Plantain  
False Western Ragweed

Row 4

Sheep Fat  
Sheep Sorrel  
Short Ragweed  
Silvery Atriplex  
Slender Ragweed  
Small Poverty Weed  
Spearscale  
Spiny Cocklebur  
Sugar Beet  
Tumbleweed Pigweed

Row 2

#### Trees

Mesquite  
Olive  
Oriental Sycamore  
Pepper Tree  
Redwood  
Scrub Oak  
Valley Oak  
Western Sycamore  
Willow  
Yellow Pine

Row 5

#### Grasses

Red Top  
Reed Canary Grass  
Salt Grass  
Small Canary Grass  
Small Flowered Melica  
Soft Chent  
Squirrel Tail  
Sudan Grass  
Sweet Vernal Grass  
Tall Oak Grass

Row 2

Firebush  
Giant Poverty Weed  
Giant Ragweed  
Greasewood  
Green Dock  
Green Sagebrush  
Lambs Quarters  
Mexican Tea  
Mugwort  
Nettle

Row 5

Western Ragweed  
White Sagebrush  
Wormseed  
Yellow Dock  
Yellow Mustard

Row 3

#### Grasses

Alfalfa  
Alkali Rye Grass  
Annual June Grass  
Barnyard Grass  
Bent Grass  
Bermuda Grass  
Broncho Grass  
Cal Brome Grass  
Canada Blue Grass  
Cheat

Row 6

#### Grasses

Timothy  
Velvet Grass  
Wall Barley  
Wild Oat

Row 3

Nettleleaf Goosefoot  
Pasture Sage  
Pickleweed  
Privet  
Quail Brush  
Rabbit Brush  
Redroot Pigweed  
Russian Thistle  
Red Orache  
Shadscale



# *Allergy in Military Medicine*

## CHART 3

### FLOWERS

Row 1	Row 2
Aster	Pink Rose
Baby Breath	Red Clover
Chrysanthemum	Snap Dragon
Daffodil	Spirea
Dahlia	Sunflower
Cladiolus	Sweet Clover
Coldenrod	White Rose
Lilac	White Clover
Lily	Wild Rose
Oxeyed Daisy	

### MOLDS

Row 1	Row 2
Alternaria spp.	Mucor circinelloides
Aspergillus flavus	Monilia Sitophilla
Aspergillus fumigatus	Penicillium Digitatum
Aspergillus nidulans	Penicillium expansum
Aspergillus niger	Penicillium roseum
Aspergillus terreus	Penicillium rubrum
Chaetomium globosum	Rhizophys
Cephalothecium roseum	Rhizophys nigricans
Helminthosporium	Torula (pink)
Hormodendrum	Trichophyton

## CHART 4

### FOOD ALLERGENS

Abalone	Black Cap	Cauliflower
Allspice	Black Eyed Pea	Celeriac
Almond	Black Pepper	Celery
Anchovy	Black Walnut	Celery (Italian)
Anise Seed	Bonita	Celery (Utah)
Apple	Boysenberry	Cheese (Amer.)
Apricot	Bran	Cherry
Arrowroot	Brazil Nut	Chestnut
Artichoke	Broccoli	Chicken
Asparagus	Brussels Sprouts	Chicory
Avocado	Buckwheat	Chili Pepper
Bacon	Cabbage	Chili Powder
Banana	Calves Liver	Chive
Barley	Cantaloupe	Chocolate
Barracuda	Caraway Seed	Cinnamon
Bay Leaf	Cardamon	Citron
Beef	Carp	Clam
Beef Heart	Carrot	Clove
Beef Kidney	Casaba	Cocoa
Beef Tongue	Cascara Bark	Cocoanut
Beet	Cashew Nuts	Cod's Liver
Blueberry	Castor Bean	Coffee
Blackberry	Catfish	Corn



# War Medicine

## CHART 4 (Continued)

### FOOD ALLERGENS

Cornmeal	Lettuce	Pomegranate
Crab	Licorice	Popcorn
Cranberry	Lima Beans	Poppyseed
Crawfish	Limbarger Cheese	Pork
Cucumber	Lime	Postum
Currant	Ling Cod	Potato
Curly Kale	Lobster	Psyllium Seed
Curry Powder	Loganberry	Pumpkin
Dandelion Greens	Mace	Quince
Date	Mackerel	Rabbit
Dill	Malt	Radish
Duck	Mandarine	Raisin
Egg	Mangoes	Raspberry
Egg (White)	Milk (cow)	Red Pepper
Egg (Yolk)	Milk (cow) albumin	Red Snapper
Eggplant	Milk (cow) casein	Rice
Endive	Milk (cow) whey	Rice (Unpolished)
English Pea	Milk (goat)	Rice (Wild)
English Walnut	Mint	Rhubarb
Evaporated Milk	Mushroom	Rock Bass
Farina	Mustard	Rock Cod
Fig	Mustard Greens	Roquefort Cheese
Filbert	Mutton	Rutabaga
Flounder	Napa (celery)	Rye
Garbanza	Navy Bean	Sabel
Garlic	Nectarines	Sage
Gelatine	Nutmeg	Sago
Ginger	Oat	Salmon
Goose	Okra	Salsify
Gooseberry	Olive (green)	Sand Dab
Grape	Olive (ripe)	Sardine
Grapefruit	Omon	Scallops
Green Pepper	Orange	Sea Bass
Ground Cherry	Oyster (Eastern)	Sea Perch
Haddock	Oyster (Olympia)	Sesame Seed
Halibut	Oyster (Willapt)	Shad
Herring	Paprika	Shrimp
Hickory Nut	Parsley	Smelt
Honey	Pea	Sole
Honey-dew melon	Peach	Soy Bean
Hop	Peanut	Spinach
Horse Radish	Pear	Squash (Banana)
Huckleberry	Pecan	Squash (Hubbard)
Juniper Berry	Perummon	Squash (Italian)
Kilney Bean	Pickrel	Squash (Summer)
Kohlrabi	Pike	Strawberry
Lamb	Pimento	String Bean
Leek	Pine Nut	Sturgeon
Lemon	Pistachio	Sugar Beet
Lentil	Plum	Sugar Cane



## *Allergy in Military Medicine*

### CHART 4 (Continued)

#### FOOD ALLERGENS

Sweetbreads	Tumeric	Wheat
Sweet Potato	Tuna Fish	Wheat Flour
Swiss Chard	Turkey	Wheat (Gluten)
Swiss Cheese	Turnip	Wheat (Gliaden)
Swordfish	Vanilla	Wheat (Glutinen)
Tangerine	Veal	Whitefish
Tapioca	Venison	Yam
Tea	Watercress	Yeast
Thyme	Watermelon	Yellowtail
Tomato	Wax Bean	Youngberry
Trout		

### CHART 5

#### EPIDERMAL ALLERGENS

Angora Wool	Goose Feathers	Opossum (Amer.)
Beaver	Guinea Pig Hair	Opossum (Austr.)
Camel's Hair	Hog Hair	Pony
Caracul Fur	Horse Dander	Rabbit Hair
Cat Hair	Hun. Stone Martin	Raccoon
Cattle Hair	Kolinecky	Rat Hair
Chamois Skin	Leopard's Fur	Seal (Alaska)
Chicken Feathers	Mink	Seal (Hudson)
Deer Hair	Mohair	Sheep Wool
Dog Hair	Mole	Skunk
Duck Feathers	Mouse Hair	Squirrel
Fox	Muskrat	Turkey Feathers
Goat Hair		Wolf Fur

### CHART 6

#### MISCELLANEOUS ALLERGENS

Alfalfa Meal	Flaxseed	Poison Ivy
Aniline	Glue	Poison Oak
Binding Twine	Hemp	Primrose
Cedar	Henna	Pyrethrum
Chalk	Human Hair	Rayon
Chicle	Jute	Red Oak
Cocoanut Fibre	Kapok	Rice Powder
Cotton	Karaya Gum	Sea Moss
Cottonseed	Klecnex	Silk
Cottonseed Meal	Lavendar	Sisal
Dust (house)	Leather	Tamarack
Excelsior	Lycopodium	Tobacco
Fir	Newspaper	White Pine
Flax	Orris Root	Yellow Pine



# War Medicine

## CHART 7 SUGGESTED DOSAGE CHART

Dose No	Date Given	POLLENS	C C	Pollen Units
		Dilution		
1		1-100,000	0 1	1
2		1-100,000	0 2	2
3		1-100,000	0 4	4
4		1-10,000	0 08	8
5		1-10 000	0 15	15
6		1-10,000	0 25	25
7		1-1,000	0 04	40
8		1-1,000	0 06	60
9		1-1,000	0 1	100
10		1-1 000	0 15	150
11		1-1,100	0 2	200
12		1-1,000	0 25	250
13		1-1,000	0 3	300
14		1-1,000	0 4	400
15		1-100	0 13	500
16		1-100	0 16	600
17		1-100	0 19	700
18		1-100	0 21	800
19		1-100	0 24	000
20		1-100	0 27	1,000

## CHART 8 SUGGESTED DOSAGE CHART

Dose No	Date Given	HOUSE DUST	C C Extract to be Used
		Dilution	
1		1-10,000	0 1
2		1-10,000	0 2
3		1-10 000	0 3
4		1-10,000	0 4
5		1-10,000	0 5
6		1-10,000	0 07
7		1-1 000	0 1
8		1-1 000	0 2
9		1-1,000	0 4
10		1-1,000	0 08
11		1-100	0 15
12		1-100	0 25
13		1-100	0 4
14		1-100	0 25
15		1-50	0 3
16		1-50	0 4
17		1-50	0 5
18		1-50	0 15
19		1-10	0 2
20		1-10	0 25
21		1-10	0 3
22		1-10	0 35
23		1-10	0 4
24		1-10	0 45
25		1-10	0 5



## PAINFUL FEET

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AND

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The problem of the treatment of non-traumatic foot ailments in the average orthopedic clinic differs greatly from that which faces naval medical officers. The naval personnel is composed of men who have on entrance into the Navy, feet which are normal in practically every respect. The problem then is to consider complaints arising in anatomically normal feet.

Before proceeding with a discussion of the diagnosis and treatment of the more common foot conditions, it may be useful to review the normal anatomy of the arches of the foot.

The foot as described in most anatomical textbooks is composed of three arches: (1) the inner-longitudinal; (2) the outer longitudinal, and (3) the anterior or metatarsal. The inner-longitudinal arch is made up of the os calcis, the astragalus, the scaphoid, the medial three cuneiforms, and the medial three metatarsals. The bony architecture is re-enforced by strong ligaments, the most important of which is the inferior calcaneo-scaphoid ligament. The arch is further re-enforced and maintained in position by the anterior and posterior muscles, which provide a sling-like effect; i.e. anterior and posterior tibials and the peroneus longus. This arch is both in weight bearing and at rest convex with its fulcrum just behind the astragalo-scaphoid joint. The outer longitudinal arch is not a true one inasmuch as during weight bearing the elements which compose it are practically resting on the ground. Its components are the os calcis, the astragalus, the cuboid, and the outer two metatarsals plus the reenforcing ligaments.

The anterior arch is composed of the five metatarsal heads, their re-enforcing ligaments and the many short muscles of the forefoot. Morton in a very excellent monograph on the foot states that to call this area an arch is a misnomer since during normal weight bearing no arch is present. The metatarsal heads bear weight directly against the ground.

About 80 per cent or more of the complaints about the feet in normal individuals will be in the longitudinal or anterior arch areas. It is perhaps best to exclude corns from this list and discuss them separately.

Usually with anterior-arch strain the most frequent complaint is



burning of the feet in the plantar area under and behind the metatarsal heads. Pain in the calves comes on after variable periods of work. There also may be associated pain in the thighs and in the low part of the back. Frequently there is a history of the patient having always been used to walking on either soft surfaces or wooden floors and of only recently having been subjected to steel or cement floors. Relief usually occurs when the patient gets off his feet.

On examination there may be tenderness on pressure under the metatarsal heads. In more chronic cases there may be calluses under one or several of the metatarsal heads and the heads may be unduly prominent when viewed from the plantar surface of the foot. In the absence of history of any acute trauma or infection the diagnosis of anterior arch strain can usually be made. The possibility of infraction of the second metatarsal head (Frieberg's disease) and also March Foot fracture should be ruled out. In questionable cases an X ray will readily make the differentiation.

In our Clinic we have experienced gratifying results in the average case through the use of a metatarsal bar (See Figure 1). This can be placed on the shoe by any cobbler who has been given proper instructions in placing it. It should be emphasized that the bar must be placed correctly. It should be just behind the metatarsal heads since its action is to slightly elevate the area behind the heads changing the plantar convexity made by the weakened arch to a concavity. This can be demonstrated by a simple experiment on the hand. Extend the fingers until the palmar metacarpal heads are prominent. Then press directly behind the heads the prominence disappears and a convexity is replaced by a concavity. It is easy to see that a bar which fits too far back or too far forward will not accomplish the purpose.

In more severe cases it may be necessary to supplement the bar with a metatarsal pad. This can be made of felt or of sponge rubber. We prefer the removable type that can be transferred upon change of shoes. The foot outline (non weight bearing) is traced on a sheet of paper (See Figures 2 and 3). The offending area is marked. The pads are designed to relieve strain in the proper area. The rubber or felt support can be glued in the shoe if the removable type is not desired. However it is just as important to see that it is placed correctly as it is with the bar.

Less frequently there may be a strain on the inner longitudinal arch. The symptoms are usually of early fatigue with pain directly under the arch and a feeling of tiredness in the calves or the front and back of the thighs. There is occasionally some low back pain. There may be



### *Painful Feet*

partial loss of the normal concavity under the astragaloscaphoid area and some tendency to pronate the foot.

We condemn the use of steel plates in these feet—especially the type sold at the corner drug store. It is our custom in the cases of very mild strain to try first the use of a Thomas heel (See Figure 1), with a

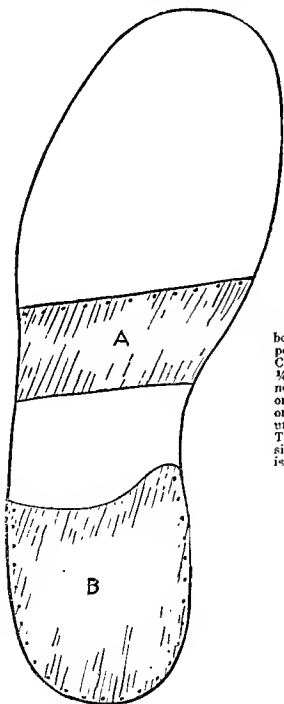


FIG. 1. (A) Metatarsal bar fits directly behind metatarsal heads (made of composition "Pancrom," Panco Rubber Co., Chelsea, Massachusetts. Size 10½" iron). ¼" thick in front wedged to ⅞" thickness in back so as to fit concave surface on sole. Bar is nailed and glued. Position on shoe should be marked for cobbler until he learns where bar is needed. (B) Thomas Heel anterior part on medial side lies under the scaphoid. Elevation is applied under medial side.



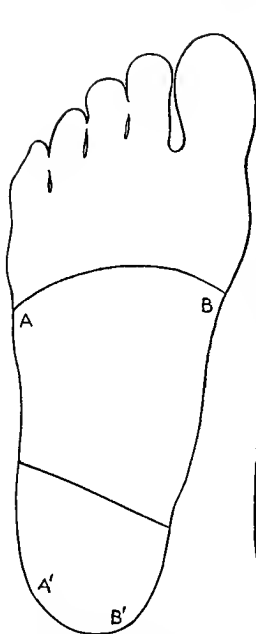


FIG 2 Outline of foot A to A' and B to B' is felt  $\frac{1}{4}$ " solid type Line AB is drawn  $\frac{1}{4}$ " behind fifth metatarsal head and  $\frac{1}{4}$ " to  $\frac{3}{4}$ " behind first head Felt is cut from outline and glued into a leather envelope (removable) Space above A is area behind fifth metatarsal head above B is area directly behind first metatarsal head

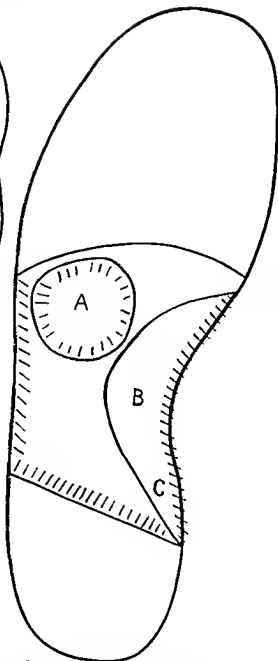


FIG 3 (A) Metatarsal pad  $\frac{1}{4}$ " solid felt, glued to the  $\frac{3}{4}$ " felt as shown in Figure 1 Pad is placed behind offending painful metatarsal heads usually more medial than shown in diagram (B) Longitudinal arch support,  $\frac{1}{4}$ " felt glued to felt base Anterior tip is about  $\frac{3}{4}$ " behind first metatarsal head Post border is well under and behind the scaphoid (C) Represents area under scaphoid Felt is skived as indicated by lines



### *Painful Feet*

$\frac{1}{8}$ " or  $\frac{3}{16}$ " inner border lift. The more advanced cases are fitted with felt inner soles of varied thickness (See Figures 2 and 3).

Felt or rubber have enough resiliency to allow the muscles about the arch to continue their normal function. Steel, on the other hand, is rigid and more or less maintains a fixed position, with subsequent atrophy of the unused groups of muscles. It is only in the far advanced, painful, rigid type of flat feet that steel or metal is useful. This type of foot is rarely if ever seen in the naval personnel.

Corns are usually the end result of ill-fitting shoes. The importance of correct size and shape, especially in our armed forces, cannot be over-emphasized. Corns in the inter-digital areas are due either to narrow shoes or the presence of exostoses on the plantar surface of one of the metatarsals. An X-ray will reveal the latter. If present, surgical removal of the exciting cause is indicated.

There are many less frequent conditions which will be seen from time to time; i.e., hallux valgus, spastic post-infectious flat foot, accessory scaphoids and weak feet and joints following an infectious process. These must be kept in mind when examining a patient with a recent history of illness.

Hallux valgus as the term implies is a deformity of the large toe.

There is usually a dislocation outwards of the first phalanx together with the production of an exostosis on the medial side of the head of the first metatarsal. In our hands simple exostectomy has been useful.

Spastic flat foot as seen in adolescents is usually a post-infectious condition. In the young adult group, the peroneal muscles, evertors, are frequently stronger than the invertors. The infectious process is thought to set up an increased irritability in the evertors throwing the foot into a valgus or flat foot position. Manipulation and application of a cast with the foot in inversion is recommended.

An accessory scaphoid is a true bone and not as formerly believed a sesamoid. It is attached to the medial side of the scaphoid. It is usually accompanied by a displacement of the attachment of the tibialis posticus tendon. The pull of the muscle is changed so that instead of inverting it tends to evert the foot. Treatment consists of removal of the accessory ossicle and reattachment of the posticus tendon so that its pull is in the direction normal to it.



# THE PROPHYLAXIS AND TREATMENT OF EPIDERMOPHYTOSIS OF THE FEET

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Commonest foot affliction of the soldier, simple friction blisters perhaps excepted, is epidermophytosis, popularly known as 'athlete's foot'. A surprising number of men have the disease chronically, especially in garrison. Recently, a company of engineers, examined by the writer during the regular monthly physical inspection, was found to be 10% infected with the fungus. The infected men were in various stages of the disease: about 30% were vesicular, 60% intertriginous, and 10% hyperkeratotic. Similar percentages have been noted in other outfits from time to time. Characteristically, the condition runs in minor epidemics. It is well known that one man, dropping soggy bits of fungus-bearing skin from his feet onto the shower room floor, can soon contaminate his entire platoon.

*Epidermophyton inguinale* and *Trichophyton acuminatum*, purportedly the causative agents of the wet and dry types, respectively, of epidermophytosis flourish under the conditions in which the modern soldier lives. As many as 100 men use a common shower in some barracks. Borrowing of shoes and socks is a frequent procedure. Although wool socks are more comfortable for the marching man, fungi unfortunately thrive better in wool than in cotton.

Prophylaxis, like freedom, requires vigilance in order to maintain its benefits. Too often the rules for the proper prophylaxis against epidermophytosis are left completely to first sergeants and latrine orderlies for enforcement. Frequent inspections of footbaths, duckboards and shower floors by medical officers is not enough. The enlisted man must be impressed that these fixtures are to be faithfully used. The attitude of the average soldier is that the ritual of using a footbath, drying his toes carefully, sprinkling powder on his feet and changing his socks daily is too much of a bother to escape such a trifling condition as 'athlete's foot'. Trifling indeed! The writer has seen an entire battalion cancel an important training march because most of the command could not walk on tender, soggy feet.

A detailed description is hereby outlined for the painstaking and continuous prophylactic measures that are required in order to keep a command reasonably free from epidermophytosis. Admittedly, a few men will always carry the organisms on their feet, no matter how thoroughly these procedures are carried out and the group treated and inspected. The



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moment vigilance is relaxed there will begin an increase in the number of infections, which, if not checked, will soon amount to an epidemic.

Floors: All floors, and shower room floors particularly, should be mopped daily with strong G-I soap, thoroughly rinsed and dried—before use, if possible. Deposits should be periodically scraped from all corners, grooves and ridges.

Duckboards: There must be two sets of these for each shower room floor. While one is in use, the other must be drying in the sun. A two inch elevation is sufficient.

Footbaths: The essential factor is that these be actually used and not sidestepped. This can most effectively be assured by building (of concrete) or placing the bath directly in front of the shower compartment so that the bather must step into it both on entering and leaving the shower. A bakelite pan, filled with a solution of calcium hypochlorite is satisfactory in concentration of 2,000 parts per million of chlorine. 1 ounce of calcium hypochlorite per 4 gallons of water will give this strength. A 10% solution of Sodium thiosulphate is also good. Solutions should be changed daily. As a part of the routine the feet should be carefully dried with a fresh towel, preferably while standing on a dry spot.

Footwear: Wool socks must be washed well, rinsed many times and sun dried as often as possible. Daily change of both shoes and socks can be done without difficulty, as soldiers are now issued two and often three pairs of field shoes. Next to shower room contamination, the repeated wearing of wet footgear is undoubtedly the most potent aid in developing a full blown infection.

Footpowder: Toughening the feet by use of alum powder will assist in preventing blisters, but not epidermophytosis. The usual G-I footpowder, containing salicylic acid, talcum, boric acid, starch and other ingredients, sprinkled on the feet and in the shoes will give some protection. A preparation containing hydroxy-quinoline (Mennen's "Quinsana") has been found to be very good. Fungicidal powders probably retard fungal growth, rather than actually destroying the organisms. Thoroughly drying the shoes is as effective as powder in this respect. Feet, of course, cannot be kept completely dry.

Treatment must be persistent. Too often, the busy medical officer, swamped with cases of infected feet, dismisses a man as soon as the interdigital spaces dry out and the pain and itching cease. Several bi-weekly inspections should be made before one is satisfied that a working cure has been obtained. An absolute cure is always doubtful, for early recurrence may or may not be from the man's own organisms; but a work-



ing cure can be maintained by diligent prophylaxis. The treatment of the three common types of epidermophytosis is as follows:

**Vesicular Type** Institution of rigid prophylaxis as outlined above. Daily, or twice daily, a solution of 1-10% alcoholic gentian violet is painted on the infected area—usually the heel or under the instep. If the condition is severe enough, the man is hospitalized for wet pack treatment. Packs are soaked in calcium hypochlorite, bichloride of mercury (1:5000), potassium permanganate (1:5000) or sodium thio sulphate solutions. Secondary infection calls for administration of one of the sulfonamide compounds, the choice of which depends on the nature of the secondary invader.

**Intertriginous Type** The white, sodden masses of epidermis between the toes are rubbed off (not too briskly!) with dry gauze. Paint each toe and its base with 1-10% alcoholic gentian violet solution, half strength tincture of iodine or 1:1000 alcoholic brilliant green solution. Freezing the areas with ethyl chloride can be tried. Caution—repeated freezing will give more trouble than the fungus! The writer acknowledges the prevalent use of salicylic acid ointments for this type but believes they add to the most discomfort of the victim. Slips of gauze placed between the toes reduce painful friction.

**Hyperkeratotic Type** The whole plantar surface including the interdigital spaces may be affected. Here, ointments are of definite value. 10% salicylic acid, half strength Whitfield's, 5-10% coal tar—all are good. A certain amount of scraping between applications is helpful in removing the heavy layers of thickened epidermis. Deep fissures are cauterized with a 50% silver nitrate solution. A solution of 10% salicylic acid in a 1:500 alcoholic solution of brilliant green has given good results in one dispensary but care must be exercised lest too frequent painting result in raw areas. Very stubborn cases will require roentgenotherapy.

### Summary

1. Epidermophytosis is one of the commonest diseases of the feet in soldiers. Uncontrolled, it will quickly reach epidemic proportions and may seriously hamper the effectiveness of a command.

2. A system of prophylaxis has been outlined suitable for the military, which must be followed diligently and continuously if garrisoned troops are to be kept free of the disease and in marching condition. The responsibility of the individual soldier in following the prophylactic routine is stressed.

3. Treatment must be persistent and several checkups made after ap



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parent cure to obviate early recurrence. Absolute cure, under garrison conditions, is unlikely, but a working cure is to be sought. A review of the standard modern treatments for the several types of the disease is given.



# HUMAN CONVALESCENT SERUM AND VACCINATION IN THE PREVENTION AND TREATMENT OF BACILLARY DYSENTERY

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The importance of bacillary dysentery as a civilian and military disease has been recognized for many years. Diarrhea, dysentery and enteritis stands tenth in the list of major causes of death in the United States. The reported morbidity incidence of bacillary dysentery for eighteen states averaged 11,220 yearly during the period 1933-1937<sup>1</sup> and amounted to 20,644 for forty-two states in 1938<sup>2</sup>. It was also interesting to note that as more cases of unclassified diarrhea were carefully studied, the majority were shown to be due to bacillary dysentery. As a military disease, it has played a role<sup>3</sup> in every major conflict since the Peloponnesian War in 431 B.C. This was exemplified during the invasion of Greece by the Persians, the campaigns of Frederick II at Brindisi in 1227, the German emperor Albrecht at Bagdad in 1439, Frederick William II of Prussia during the French Revolution in 1792, Napoleon in Russia, during the Crimean War, the Civil War,<sup>4</sup> and the British campaigns in Puerto Rico in 1598<sup>5</sup> and Gallipoli in 1918<sup>6</sup>. Some idea may be gained of the disabling effects of bacillary dysentery from the experiences of the British in Macedonia, Egypt and Mesopotamia during the World War. Although the mortality was only 2.7 per cent, the average period of invalidism for a group of 2000 troops was 141 days. A report by Korschegg<sup>7</sup> on the recent German campaign in Poland indicates a similar trend.

During the past decade there have been a number of advances in the clinical and laboratory study of bacillary dysentery. Adaptations to climate and virgin soil have given a somewhat changed character to the disease. New clinical forms<sup>8</sup> and a characteristic three stage progression of pathology<sup>9</sup> have been described. A clinical reclassification based upon the degree of severity rather than bacteriological types involved now seems expedient since strains hitherto regarded as of low or doubtful pathogenicity have been found to be extremely virulent in some instances (e.g. Sonne Duval)<sup>10</sup>. Recent studies on *B. alkalescens*,<sup>11</sup> originally regarded by Andrewes as non-pathogenic, indicate definite pathogenicity and the presence of two antigenic factors, one identical with the Flexner organism the other type specific.<sup>12</sup> Yearly world surveys since 1933 by the International Dysentery Registry have resulted in a wider knowledge of the distribution and nature of the disease as observed by public health



officials whose personal observations have been most illuminating. Careful analysis of this data has resulted in the formulation of a seven point program for the prevention and control of infectious diarrheas.<sup>13</sup> Finally, clinical and experimental studies on the immunology of bacillary dysentery have revealed new possibilities in prevention of the disease in the human. It is with this concept that the present discussion is concerned.

In the course of clinical and experimental investigations during the past decade, considerable evidence was presented pointing to an acquired immunity in bacillary dysentery. In endemic areas natives often appeared to be immune, the disease being perpetuated largely by newcomers, previously uninvolved children and carriers. There is considerable doubt as to the existence of so-called "healthy carriers" in bacillary dysentery. Our experience has been that careful and repeated sigmoidoscopic examinations usually reveal active intestinal lesions. An excellent illustration of acquired immunity may be drawn from the Jersey City Flexner epidemic of 1934.<sup>14</sup> The rise started about July 22, reached its peak on August 11 and then rapidly declined so that by the end of the month the epidemic was practically terminated. A sharp secondary rise occurred, however, after Labor Day, when there was a marked influx of children returning from their summer vacations. The second outbreak was confined chiefly to these newly arrived non-immunes. Similar findings have been reported by McGinnes.<sup>15</sup> Among the British troops in Egypt, bacillary dysentery is largely confined to new arrivals.<sup>16</sup> In institutions, where the disease often persists for years similar conditions prevail, particularly among infants, the feeble minded, aged and psychotic. In two such institutions coming under our observation the preponderance of the disease among recently admitted individuals was very striking.

In view of clinical impressions such as these the possibility of active immunization or passive transfer appeared quite feasible. In order to test their validity in laboratory animals, a series of experiments was instituted.<sup>17</sup> The findings may be summarized as follows:

The serums of rabbits actively immunized by vaccination, protected mice against 10 M.L.D. of the same toxic Flexner strain whether the latter were injected previously or simultaneously with the immune serum. Thus, where intraperitoneal injections of serum and organisms were made a few seconds apart only 10.2 per cent fatalities resulted as compared with 100 per cent in the unprotected group. Moreover, the immune serum could be injected as much as five days before the organisms and still afford excellent protection. The fatalities were 8.3 per



cent as compared with 100 per cent among the normal serum and no serum controls. On the other hand the immune serum administered as soon as four hours after the injection of 10 MLD was of little avail the fatalities being 80 per cent. Active immunization of a separate group of mice also resulted in a considerable degree of immunity, the fatalities following 10 MLD nine to fourteen days after the last vaccine injection being only 20 per cent as compared with 90 per cent in the unvaccinated mice.

The application of these findings to the human await extensive field tests before final conclusions can be drawn. In our preliminary work however extending over a period of approximately seven years certain premises appear to be justified.

- 1—Man like some experimental animals after recovery from infection with bacillary dysentery appears to be resistant to subsequent attacks.
- 2—It takes less immune body to prevent the disease than to cure it.
- 3—Immunity in bacillary dysentery is highly type specific.
- 4—Type specific therapeutic serums are more effective than polyvalent serums.

5—The best results are obtained when they are used early and in adequate quantities.

6—Type specific serum and to a lesser degree polyvalent serum are effective agents in the prevention of bacillary dysentery during outbreaks.

7—In epidemics human serum from recovered cases is highly type specific and therefore of great value in prophylaxis and therapy.

8—Vaccination affords considerable protection in the human and is highly strain specific.

In the acute disease therapeutic serum from recovered human cases should be administered intramuscularly within the first twenty four hours and in a dosage of 100 to 200 cc for adults depending upon the severity of the disease. Where specific indications exist double these quantities of whole blood may be used intravenously after tests for compatibility and syphilis have been made. For prevention of the disease in contacts 25 to 50 cc of serum appears to be adequate. In epidemics there is generally no lack of volunteer donors this being particularly true among military forces. Under actual working conditions it is a rather simple matter to have pooled serums on hand for both prophylactic and curative therapy. The desirability of such an arrangement is evident since hygienic and sanitary arrangements under conditions of active war service in combat zones are necessarily too limited to be relied upon as the sole methods of prevention of bacillary dysentery. The use of monovalent type specific rabbit or horse serum would also



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be of considerable value where the time factor in preparation is not important.

Human blood is collected from convalescent acute cases at about the end of the third week under aseptic precautions in one pint sterile wide mouthed square bottles. The blood is allowed to clot at an angle of approximately forty-five degrees, the serum drawn off, transferred to 250 c.c. centrifuge bottles and centrifuged in a two or four place head (International No. 2). The clear, Wassermann or Kahn tested serum is then preserved with 0.25 per cent phenol or 1:10,000 merthiolate in rubber capped 120 c.c. pyrex nursing bottles and kept in the ice box until used. Pooled serums are apt to be somewhat better than serums from a single case, particularly in double infections (some cases have even been reported with three strain infections). Moreover, the value of individual serums varies with the virulence of the infection and immunological response of the donor.

In handling sporadic cases among civilians, it was at first deemed advisable to segregate professional donors whose blood exhibited high agglutination titers against *B. dysenteriae*. This was based on the assumption that such individuals probably had at one time or another an infection with the strain against which they showed the highest titer. The scientific limitations of such an assumption were obvious but in actual practice it seemed to work out rather well. Through the co-operation of the Blood Betterment Association, the method proved satisfactory until the donors moved away or otherwise proved beyond control. Reliance was then placed upon monovalent animal serums or vaccinated donors who had been reserved chiefly for patients with chronic bacillary dysentery.<sup>15</sup> Because of the time factor involved, we have found it expedient to keep fresh endemic or epidemic strains constantly on hand. This has been made possible through the co-operation of various public health officials and bacteriologists in the United States and many foreign countries. In this manner, the International Dysentery Registry has endeavored to maintain a constant supply of recently isolated strains with full knowledge of their source and considerable information as to the associated clinical manifestations.

In dysentery due to the Shiga organism the prophylactic or therapeutic use of either commercial or human serum is indicated since the strains constitute a homogeneous group and are good toxin producers. Davison<sup>16</sup> found the prophylactic use of anti-Shiga serum effective during an epidemic in Saskatchewan in 1936. The Flexner organisms, on the other hand, form a heterogeneous group with rather marked type specificity and inconstant toxin production. The relative value of mono-



valent convalescent human serum is therefore higher in Flexner infections than in Shiga infections as compared with polyvalent commercial serum. Since B dysenteriae Flexner comprises by far the bulk of dysentery infections the world over at the present time,<sup>20</sup> the practical importance of human serum is evident. As part of our military defense program it appears feasible to prepare in advance of actual requirements monovalent stock human serums against Shiga, Schmitz, Flexner V W X Y Z Sonne Duval, Newcastle and Alkaescens strains. This should not prove difficult since the geographic distribution of the disease and types of infection are known through the yearly surveys of the Registry.<sup>21</sup> A supplementary source of pooled anti-dysentery serums may be found in the Red Cross serum bank now in process of formation. Each specimen is set up against alcohol killed monovalent antigen<sup>22</sup> in a single dilution of 1:160, for all strains except the Shiga and Sonne Duval where 1:80 should be used. Those serums exhibiting the titers indicated may be marked accordingly and set aside for prophylactic and therapeutic purposes where fresh serum is not available or feasible. Here again the usefulness of high titer serum is based entirely on practical experience, being decidedly superior to ordinary human low or non titer serum.\*

Active immunization by vaccination holds possibilities of inestimable value to both the civilian and military population. Although there has been considerable difference of opinion on the subject, we have repeatedly been impressed with its effectiveness both experimentally and in small outbreaks. The experimental work reported above<sup>23</sup> has been corroborated by Prigge<sup>24</sup> who also advocates the vaccination of humans. Field tests by Paddle<sup>25</sup> in England, Van Hoof<sup>26</sup> in the Belgian Congo and Fembaer<sup>27</sup> in the Netherlands Indies point to the efficacy of vaccination in endemic areas.

The effects of vaccination with monovalent and polyvalent dysentery strains on the production of agglutinins have also been studied in rabbits including variable amounts of the Andrewes V W X Y Z components in the Flexner strain as well as combined mixtures with B, typhosus paratyphosus A and B.<sup>28</sup> The results may be summarized as follows:

1—Alcohol killed cultures of B dysenteriae injected subcutaneously give rise to higher agglutinins in the experimental animal than viable broth cultures.

2—This may be partly due to the greater concentration of alcoholic

\* If high titer bloods may be pooled as lyophilic plasma for better antibody preservation thus fitting in with the present policy of the Red Cross plasma bank.



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antigen, which, however, is devoid of toxic effects.

3—Intravenous inoculations of either broth or alcohol killed cultures result in higher titers than those obtained by the subcutaneous route but the toxic effects are more pronounced.

4—Attention is called to the "enhancing value" of a single intravenous inoculation supplementing subcutaneous vaccine administration.

5—Inoculation of polyvalent mixtures of 3/20 parts each of *B. dysenteriae* Flexner V, W, X and Z with 8/20 parts Y resulted in comparable or higher agglutinin titers than Y alone.

6—The use of equal parts of V, W, X, Y, and Z compared favorably with polyvalent or monovalent strains specified in conclusion 5.

7—The combined use of six parts of Flexner V, W, X, Y, and Z in the proportions specified in conclusion 5 plus two parts each of *B. typhosus*, paratyphosus A and B alcohol killed cultures proved equally satisfactory.

The production of agglutinins does not necessarily bear any direct relationship to immunity. These studies merely suggest a serological response which, taken in conjunction with serum protection experiments, hold some promise for the future use of combined TPD (typhoid-paratyphoid-dysentery) antigen in vaccination against these diseases. Our experience with oral vaccination has been too limited to warrant any definite conclusions. Though based upon Bresredka's theory of local tissue immunity it appears quite likely that any favorable effects are due to actual absorption of toxin, with systemic response. This certainly appears true of the rectal administration of large doses of heat or alcohol killed vaccine which we have used for more than ten years. It is not as effective, however, as parenteral injections.

### Summary

1. Clinical and experimental observations indicate the existence of an acquired immunity in bacillary dysentery.

2. Active and passive immunization by the use of vaccine and human convalescent serum is described.

3. The application of these findings to the prevention and treatment of bacillary dysentery await large scale field tests for their final evaluation.

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## CHIGGER AND JIGGER BITES

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The purpose of this discussion is to consider the problems presented to medical officers with field forces in the southern states by two first class minor pests. They are the Chigger or "harvest mite" of the family Trombidiidae; and the Jigger or sand fly of the family Psychodidae.

### POINTS OF DIFFERENTIATION

#### "Harvest Mites" or "Chigger" *Trombidiidae*

1. Larval Acarid—not an insect.
2. Crawls only.
3. Not a blood sucker.
4. Attaches to skin surface.
5. Bite any time they find a host.
6. Habitat: Open fields, grass, underbrush, berry patches, leaves of small trees.

#### "Sand Fly"—"Jigger" *Psychodidae*

1. An insect.
2. Gnat-like fly.
3. Female—a blood sucker.
4. Burrows into the skin.
5. Nocturnal in their biting habits.
6. Habitat: Vicinity of old buildings, barracks, rubbish.

Both are widely distributed throughout the warm regions of the world and are quite prevalent about the camps in the south where large numbers of troops are concentrated.

Since even among medical officers these two mites are quite often confused, and because their bites produce irritation and discomfort which has an unfavorable influence on the morale and physical well being of troops, a consideration of the prevention and treatment of these bites should be of real value.

At the outset, let us say that our observations have been made while on duty with a regiment of field artillery, and so necessarily lack laboratory study or investigation.

At the beginning let us set down some points of differentiation between the two, and then consider them separately.

The chigger is the six-legged red larva belonging to the order Acarida, family of Trombidiidae. The adult form is an eight-legged scavenger which lives on plants and decayed vegetation. It does not become parasite on man or animals. Often spending the winter underground, it emerges in the spring and deposits eggs on the ground and low-lying plants. In about four weeks, the eggs hatch out the six-legged larval forms with which we are concerned. These minute larvae are quite active and can crawl at the rate of about four inches per minute. It appears that they must become parasites in order to survive. Their hosts can be either warm or cold blooded animals. Thus they are found attach-



ing themselves to man domestic and wild animals, rodents, ground nesting birds, reptiles and insects

They do not change hosts but remain attached from two to four days, if not disturbed, and then drop off. While attached to the skin they secrete a substance which digests or liquifies the epidermal tissues upon which they become engorged before dropping off to go into a pupal form. After one or two weeks a colorless, eyeless, eight legged nymph emerges from the pupal form. This in turn changes to a second nymph form in a few days. The latter in two or three weeks becomes an adult. Since there is only one generation of chiggers each year, and since the adult forms do not infest man or animals, the larval forms torment us during a limited season only, the hot months of June, July and August.

The soldier on field training is frequently in contact with the ground grass, underbrush, berry bushes and low trees so his chances of becoming infested with chiggers is very great. A check made on a group of 200 soldiers who spent a ten day period in the field during July 1911, revealed that seventy eight per cent were annoyed with three or more chigger bites on their return to garrison, the intense itching persisted from three to five days, and most of the lesions required another week to heal.

The majority of the bites were located from the ankles up to the belt line being most numerous below the knees. It appears that the mites attach themselves at spots where they meet an obstruction, such as a constricting garter or belt. In some instances the invasion was from the neck and shoulders downward. Most of these men had rested for several hours, lying flat upon the ground.

The larvae prefer areas where the skin is thin, and rarely attack the face or hands. They may attach themselves at a follicle but do not seek out the pores as is generally believed. Their small sizes makes them invisible to the naked eye, but a low power hand magnifying glass will show them as a tiny red speck located at the center of a bite. This larva does not burrow, but attaches itself to the skin surface with a rather efficient mouth. The fierce maddening itch is not due to the initial bite but is caused by the liquifying of the epidermal tissues by a digestive secretion which the larva injects into the wound.

Many soldiers who had spent but part of a day or night in the fields did not notice the bites until twelve to twenty four hours after their return to the barracks, misleading them to believe that their quarters were infested. But since the mites may remain active in infested clothing the late appearing bites were due to mites being brought in from the fields in this fashion. This was definitely proved by the physical



### *Chigger and Jigger Bites*

inspection of a group of men who had not been in the field. These men were entirely free of lesions, while troops in a neighboring barracks, who had spent part of a warm day and night in the field thirty-six hours previously, had a seventy-five per cent incidence of bites.

There were three distinct types of lesions noted.

1. An indurated papule, with considerable redness and swelling, characterized by intense itching.

2. A papulo-vesicle with moderate redness, induration and swelling, characterized by less intense irritation and itching. After rupture of the vesicle, the irritation and itching subsided gradually, but the lesions discharge a serous fluid for several days.

3. A large vesicle or bleb from one half to two centimeters in diameter, which is not unlike the blisters seen with a second degree burn, or the trophic blisters which appear with the swelling in some cases of fracture of leg or arm. However, the swelling and redness around this type of lesion was the least of any of the three types, and the itching was practically nil. If the tops were taken off these lesions in toto, superficial ulcerations resulted. These healed rather slowly, but if the serum was allowed to drain out through a small dependent puncture and the tops allowed to collapse, these lesions then healed much more kindly.

Only in a few instances were we able to recover the mites from the bites for mounting and microscopic study. We believe that they become engorged with tissue juices rather rapidly when active, and drop off the skin after a few hours. So they can rarely be found in the lesions unless the soldier reports quite early. Heat stimulates their activity, as the warmer the day or night the more rapidly the lesions developed after infestation.

### **Prevention**

Prevention of chigger infestation is preferred to treatment. Most of the officers, and a great many of the enlisted men were anxious to protect themselves from further bites once they had been through a siege of the persistent, maddening itching which a group of bites entailed.

It was first thought that wearing protective clothing in the field would keep out these parasites. Canvas leggings were worn by all troops on field duty. They fit rather snugly around the shoe, ankle and calf, but still the mites could get in. Because of their small size they require very little opening to reach the skin surface. In warm weather it is impossible to wear clothing tight enough at the arms and ankles to keep them out.



Powdered sulfur is known to be the best repellant—our problem was to make it available in an effective form, and one which would not require too much trouble and effort in its applications. Dusting sulfur on the legs, arms, under the arm pits and about the groin proved non-effective because it was soon lost by perspiration, and also produced a dermatitis about the intertriginous surfaces.

The use of a wash cloth impregnated with fine sulfur which when used as a bath produced a sulfur foam lather was suggested, and seemed an ideal solution. However, it is impractical for field forces, as the necessary time and bath facilities are rarely available. This preparation was originally put out for the treatment of scabies, as a leisurely procedure upon retiring. It is quite obvious that troops going into the field could not be expected to take time for this application.

Combining sulfur in a lotion with calamine and phenol was found to be an effective protection when painted on the legs and arms. This too proved to be impractical for a large group of men because of the time factor involved in applying it and waiting for it to dry. Handling a liquid was an added drawback with this method.

Adding sulfur to a grease as petrolatum was satisfactory and could be applied rapidly by the individual soldier, but the grease made the skin surfaces too oily and soiled the clothing.

We began searching for a base which would mix well with sulfur and leave a fine film of it on the skin surface without the objectionable features of grease. Several of the various commercial preparations of vanishing cream were tried. Most of them contained too much air and almost vanished in the process of mixing the sulfur with them, or else they did not take up the sulfur well and the resulting product was irregular or lumpy.

Finally we used a commercial preparation of high grade vanishing cream known as Hazeline Snow. Mixing one part of powdered sulfur to four parts of this preparation we obtained an ideal mixture. When applied to the skin it leaves an almost invisible film of sulfur. It can be applied to a wide area quickly and dries quite rapidly. This proved to be very effective as a chigger repellant and besides was cool and refreshing to the skin. A small amount covers a large surface and re-application could be easily accomplished. It was applied before going into the fields and then re-applied after a soapy shower upon return to camp. None of the men who followed this treatment developed chigger bite lesions while men of the same groups who were unprotected developed numerous lesions.



## *Chigger and Jigger Bites*

### **Treatment**

We also found that if the sulfur cream was applied to the bites early it ameliorated the pruritus and hastened the healing, thus it came to be a useful adjunct in treatment.

During the summer months in the south the treatment of chigger bites vies with the weather as a frequent and popular topic of conversation. Most everyone has his own favorite remedy. Bacon rind and kerosene oil is the choice of the colored folks. A Virginia artillery officer passes on a refrain which, as a boy, he recalls hearing the negroes chant—

"Got my meat skin laid away.

Grease my chigger bites every day."

Tobacco juice also has its adherents as a preventive and treatment. Ammonia, strong salt water, iodine, collodion and strong soap lather are but a few of the many remedies advocated.

There are three main missions to be accomplished in treatment.

- (1) The removal of the larvae from the skin surfaces.
- (2) The relief of the severe itching and irritation.
- (3) The prevention and treatment of secondary infection.

To remove the larvae present on the skin, a half hour of bathing, using plenty of soapy water, and then, after drying, a light application of the sulphur cream is recommended. There should be a complete change of clothing as active mites may remain in infested garments.

Since the bites may cause intense itching and irritation as long as a week after the parasites have been removed, it is imperative to allay these symptoms and help to prevent secondary infection introduced by scratching. For this purpose the lesions are sponged off with 70 per cent alcohol several times a day, and a mild antiseptic, antipruritic ointment applied. Boric acid ointment to which has been added ten grains of phenol and five grains of menthol to each ounce of ointment makes a good preparation. It is spread on lightly and a little borated talcum powder dusted over the surface. It may be re-applied as needed to control itching. The soldier is cautioned against scratching, as it appears to spread the lesions, increases or prolongs the itching and makes secondary infection more likely.

The lesions that became infected were usually the ones about the ankles. The rubbing of the shoe tops also appeared to be a factor in introducing infection. *Staphylococcus* was the usual secondary invader producing a localized furuncle. However, several cases of cellulitis with lymphangitis were encountered, evidently due to the streptococcus. These



infected lesions required bed rest with elevation and stuffed gauze dressings moistened at intervals with warm boracic acid solution. While there were no serious results they caused days lost from duty, so their prevention, if possible assumes considerable importance.

## "Jigger"

Now the Jigger or sand fly should not be confused with the larval acarid or Chigger which we have just considered. It is a small insect which flies, and the female sucks blood from its host. A scientific name for this tiny gnat like fly which gives a hint to its activities is *Phlebotomus*. There are many species, one of which is known to be the insect vector of sand fly fever. They are most prevalent when and where the atmosphere is hot and humid.

The impregnated female attacks a variety of host, both warm and cold blooded animals, and especially the human being and the pig. She burrows into the skin as a minute scarlet mite, and is often referred to as the red bug. Soon after burrowing in she swells to the size of a pea, due to ingested blood and the maturation of the eggs. Blood appears to be necessary for the development of the eggs in the female and makes her a persistent and vicious blood sucker. She attacks man on the hands, wrists, ankles or neck but will bite any exposed portion of the body. As she burrows into the skin the two posterior segments of the body plug the opening so that the eggs are discharged on the skin surface, and are not embedded underneath the skin, as popularly believed. After becoming engorged with blood the female searches out warm moist dark places to deposit her eggs. Cracks or crevices in old buildings or barracks in rubbish and debris about buildings are her favorite sites. About 40 eggs are deposited separately over a period of several days. Usually the insect dies after oviposition.

In hot humid weather the eggs hatch in from six to nine days. This insect shuns light, and so does her blood sucking at night. She will not deposit eggs in the presence of sunlight, but artificial light, unless it is very intense will not hinder her activity. During the day they hide and rest in dark, out of the way places inside and outside the buildings. They are limited fliers and do not travel far from their breeding places. They cannot fly well against a breeze, and so are not active when the wind is up.

The bites of the sand fly produce lesions quite similar to those produced by the harvest mite, causing about the same amount of itching and discomfort.

Prevention is based upon the elimination of breeding and hiding



places. Clearing up of rubbish around barracks and buildings, admitting sunlight to dark places, and filling up cracks and crevices help in keeping them away.

Being of small size they can pass through screening and mosquito netting. Muslin can be used in place of netting to exclude them, but this is uncomfortable on hot nights when the sand fly is active, so its use is not practical. In rooms where an electric fan is available, it may be used to create a breeze which will keep the insects out.

The repellants which are most useful are camphor and sulphur. The camphor can be put up in small bags and rubbed on the exposed surfaces at night. A solution of camphor, menthol and phenol painted on the skin is also of value.

The sulfur cream makes an excellent preparation for application as the insects are destroyed by small amounts of it. Sulphur fumigation can be used to destroy the insects hiding in barracks or buildings.

Sand fly fever is transmitted by one of the many species; *Phlebotomus pappatasi*. There are several of the other species which are thought to be capable of transmitting the disease also, however, this fever is rare among soldiers of the United States, and therefore is not a problem.

It is an acute infectious disease, with sudden onset, fever of a few days' duration, headache and pain about the eyes, with congestion of the face and injection of the conjunctivae. There is backache, loss of appetite, and marked mental depression and general malaise associated with this fever. It is a self-limited, non-fatal disease. The incubation period varies from three to seven days.

Sand fly fever is due to a filterable virus which is present in the blood during the first day of the disease only. A period of six or seven days intervenes after the insect has bitten a fever patient before it can transmit the infection to another person. A certain degree of immunity is conferred by one attack. This is not permanent in all cases, as second attacks are common, but they are usually milder than first attacks. The control of sand fly fever depends upon the elimination of the insects from around barracks and buildings. Known cases should be completely protected, and isolated to prevent the sand fly from gaining access to them, particularly during the first day of the disease.

In the use of sulfur in the prevention and treatment of these bites the possibilities of sulfur irritation and toxic effects must be considered. In our experience, while using the sulfur in powder form, a number of cases of dermatitis and folliculitis were noted, particularly about the intertriginous surfaces. But with the sulfur cream there were no ill effects experienced. Since day after day application was not necessary



because of the short duration of most field maneuvers, the dangers from repeated applications of sulfur did not have to be considered seriously.

### Summary

Attention is called to the importance of two minor pests which have an adverse effect on the morale and physical well being of field troops during the summer months

The differentiation between "Chigger" bites, inflicted by a crawling larva, and jigger bites inflicted by a flying insect is stressed

A consideration of the prevention and treatment of these bites is outlined.

Combining powdered sulfur in a vanishing cream base is advanced as an easy, practical and effective means of its application to prevent and treat these lesions.

### Conclusions

The problems which confront the medical field officer are not always the major illnesses and injuries. These are quickly disposed of by evacuation and hospitalization. It is the care of minor lesions, which, affecting large numbers of soldiers, tax the patience and ingenuity of the medical officer. Such minor maladies exert a depressing influence on the morale and physical well being of troops. To adopt a "Hard boiled," "You're in the Army now" attitude in dealing with soldiers undermines their confidence in the doctor. If he does not do his best to solve their minor medical problems, they soon come to doubt his ability to handle their major ones.

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## MALINGERING

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A comprehensive treatise upon malingering is impossible in this present study which seeks to invite the attention of the medical officer to this multiphased problem and encourage his further study of it.

Irreparable injustice is perpetrated whenever actual physical or psychiatric ailments are misjudged as malingery; equal injustice results whenever malingering "racketeers" pass undetected. The author asks the reader ever to remember that he does not intend to infer that "malingery lurks in every complaint"; likewise, he asks that the omission of any presentation of the science and art of differential diagnosis of "legitimate" disabilities, in the interest of brevity and continuity, be not construed as denoting his assumption that the majority of allegedly ailing or disabled individuals encountered by the medical man are guilty of criminal conspiracy or have arrived at their decrepitude through malingerosus acts. Physicians of long experience, both in civilian and in military situations, will readily proclaim that pretension and malingering constitute but a small percentage of the cases of disability they have encountered; equally they will admit that these few cases of malingery proffered about the most difficult problems they handled—not only in the detection of simulation where present but, equally, in properly identifying actual distress where existent.

Let us commence our study of this problem with the definition of malingering proffered by Webster's New International Dictionary:

"MALINGERING (or malingery): the act of a sailor or soldier who feigns himself sick, or who induces or protracts an illness, in order to avoid doing his duty; hence, in general, one who shirks his duty by pretending illness or inability."

Such is quite clear—as *far as it goes*—but a moment's consideration serves to show that it is incomplete and that, in addition, it invites the misconception that such act is peculiar to the military service, which is patently contrary to accumulated evidence. *Furthermore such definition actually covers only one-half of the domain of malingering. It is equally malingery, and of equal import, if a person endeavors to feign health, in order thereby to gain some advantage to which, in truth, he is not entitled.*

Malingery is actually more diversified than the casual observer appreciates; each and everyone of us has been guilty of it betimes, to a



limited extent both in civil and military life, and in the feigning of both disability and competency. Thus when seeking our commissions as officers if we possessed any slight defect or disability, however trivial we did our utmost to conceal or discount it during our physical examinations. All who have had experience with civilian compensation cases accident or life insurance matters and in so called negligence cases or damage claims have encountered instances wherein malingering was being practiced either by the claimant to bolster his claim, or by the defendant to reduce or escape the penalty or judgment sought. The much publicized cases of ambulance chasing and accident rackets are essentially projects which require expert malingering for success.

I well recall the claimant in a damage suit of some years ago who procured a judgment of \$1 500 for a seeming permanent ankylosis of the right wrist consequent upon an auto accident. Months later, when called to attend her medically I noted an entirely normal wrist. My insistent inquiry then discovered that she was double jointed and had practiced the simulation of the alleged deformity to procure the cash for a down payment upon her home. Even the X Ray films in this instance were misleading only a survey under general anesthesia would have detected the malingering.

With equal skill a simulation of normalcy may be practiced where the advantage accrues therefrom. As to such I mention a school teacher long a private patient of mine who continues to date in her position despite an actual disability which should have retired her long years ago. This woman is stone deaf but is such an accomplished lip reader and so adroit at avoiding any embarrassment because of her defect that she has eluded discovery. Sometimes if the defect be incapable of such concealment an adroit campaign of persuasion or diversion of the examiner's attention may attain the desired goal for the malingerer. Such instances may prove most embarrassing to an examiner and require his utmost skill and diplomacy.

Not infrequently applicants for life insurance or for some type of employment or assignment to some special duty will do all in their power to conceal a known disqualifying defect. Conversely we encounter those who present such a defect as the basis for a compensation or damage claim alleging such to be the direct result of their employment or accidental injury when in fact they know such defect to have existed long prior to the causative occasion alleged. Thus to the pretension or concealment of defects and disability we must add the misinterpretation of any such as an additional malingering possibility.

Anything from ingrown toenails to falling hair may be simulated or



concealed, and may concern any of the functions and structures of the body, depending upon the requirements of the specific project attempted and the knowledge and skill of the malingerer. While some pretensions may readily be detected, there are those referring to particular organs, functions and structures which only the most accomplished expert with specialized equipment can recognize and expose. Hence the problem of malingery cannot be brushed aside as "a routine matter for determination" and nobody need feel unduly disgruntled if, betimes, such an imposter succeeds in evading detection by him. *The wisest of men* are those who *admit they can be fooled* but see to it that the same trick does not fool them too frequently.

Let us now consider some forms of malingery commonly encountered in military situations and outline the proper means for their detection. First we shall study those situations wherein a simulation of health and normalcy may be attempted. Many different impulses may cause a man to seek acceptance into military service despite disqualifying defects he knows are possessed. Other than pure patriotic motives, it may be a desire to emulate the enlistment of relatives or friends, the desire for the educational and occupational training the army affords, or the promise of good food and housing and a steady income with escape from the highly competitive environment of civilian communities. Again, it may be a conspiracy to attain army acceptance in order, later, to obtain a pension or disability allowance by then revealing the defect or disability and setting up a claim for such as having been acquired "in line of duty."

To attain admission to "special services" with higher physical requirements, even more strenuous and crafty concealments may be attempted. Such are witnessed in examinations for West Point, Annapolis, the Air Corps, or Submarine Service. Even if the examiner discovers a defect, despite the effort to conceal it, such a candidate will often argue its insignificance to the point where you will almost be persuaded to delete such from your report. Beware of such pitfalls, for the defect is certain to be revealed by a subsequent examination and the mention of your miscue will not improve your "201 File" when commentary thereon reposes there, as it inevitably will.

Lastly, when a command is about to change station, or a casual group of officers or enlisted personnel is preparing to travel en masse, a member of such unit or group who is then in hospital or on sick call, realizing his predicament, will often feign recovery so he will be permitted to travel with such party. The very last thing the experienced officer or soldier desires is to be "casualed" away from his assigned unit



and thus lose contact with his comrades. A similar situation will obtain at the time of discharge from the army when a man will want to travel home with his buddies. I witnessed many such episodes in the latter months of the First World War.

Many of us have encountered examinees who had memorized the letters upon an eye test chart or who sought to punch a pin hole through the blinder affixed over their one good eye during such testing. Likewise, we have met those who drugged themselves with opiates to estop a diarrhœa, took barbiturates to reduce an elevated blood pressure, digitalized themselves to correct a tachycardia, used atropine, sulphanilimid or an astringent to suppress an urethral discharge, or conspired with an onlooker to prompt them during a sight or hearing test. Likewise, we have met those who denied a prior serious illness, even though its scars or sequelae were still evident. Pretensions to normal health by those actually afflicted with functional ailments is, fortunately, infrequent during routine physical surveys, for such are almost unidentifiable except through prolonged observation. I recall one such instance of unique interest that of an enlisted man of the regular army who remained in active service many years eventually becoming a Technical Sergeant, despite the fact that he was an epileptic. His attacks of grand mal epilepsy always occurred at night and his barrack mates collaborated with him in the concealment but, when eventually he suffered such an attack while engaged in a night field exercise, his affliction was recognized and his retirement followed. However, he receives a pension to this date.

The younger medical officer has yet to learn that it is the usual occurrence when an enlisted man or an officer of the Services—who is a real soldier at heart—develops a disability or defect which will cause his compulsory retirement, he will frequently endeavor to hide such disability and, when detected, will 'move Heaven and Hell' to have such disability waived. Such instances are sad indeed and require both skill and commiseration for proper disposition. Recently, a high ranking Reserve Officer, in similar situation, and after having failed to secure a waiver of his disability after successive importunings of all the military authorities, political friends, and others he could approach, asked that I advocate such waiver to the Surgeon General, since he knew I was assigned to S G O and inferred that I might possess "influence." Obviously, I declined but my refusal had to be most adroitly worded lest it be misconstrued and eventuate in undesirable repercussions. I am certain that other medical officers of the senior grades have had similar experiences to my own which show these problems pertaining to various types of malingerers ever more numerous, intricate, and more trying to handle.



Let us pass now to a consideration of that form of malingery wherein the intent is to simulate a disease or defect, or prolong a disability, for the man's own selfish purposes. Such attempts are now being encountered in the physical examination of enrollees under Selective Service, as they were in all former wars when conscription was instituted. The draftee, if a 'slacker,' or desirous for any reason of postponing his entry into the military service, will first set up a formidable array of reasons for a deferred civil classification—such as alleged dependents, employment in an 'essential occupation,' financial obligations, or what-not—and, if all these fail him, then the tribulations of the medical examiner begin, and they do not cease after his induction into the service. A proven malingerer will ever thereafter grasp every opportunity to evade duty and so a succession of pretensions must be expected of him so long as he remains in the army. In desperation, such malingerers will sometimes proceed to bodily mutilations to disqualify themselves from military service. Instances wherein a man has chopped-off fingers or an entire hand, a toe or even an entire foot, has had all his teeth extracted, punctured his own ear-drum or blinded one eye with acid or caustic alkali, has produced a rectal, oral or nasal ulceration by chemical or mechanical agents, has slashed a tendon in his arm or leg, or even deliberately fractured a limb, are on record. (Vivid description of such occurrences in the Penal Colony in French Guiana is found in the recent "best seller," "Dry Guillotine.") Hence, it is the duty of the medical officer to determine whether any defect or disability presented has been intentionally and criminally induced. Upon such determination rests the legal status of the examinee and his proper disposition.

Similarly, soldiers in service may commit such mutilations to avoid participation in a battle or escape a distasteful detail, or to achieve discharge from the service for permanent disability with its resultant pension. While it is not to be inferred that such instances are numerous, it is to be stressed that they do occur and that each such malingery which escapes detection perpetrates a gross injustice upon all honest and deserving soldiers and imposes an unjust burden upon the taxpayers. Official recognition of the importance of this subject is denoted by the section thereon which appears in the manuals issued in Local and Appeals Boards under the Selective Service Act, and the inclusion of such subject in any approved instruction course for medical officers.

Deafness is commonly simulated and may be detected by catching the malingerer off-guard by a process of confusion, or by the adroit use of a stop-watch, or by having the suspect's conduct observed while awaiting his turn for another testing in a room filled with other candidates



with whom if possessed of normal hearing he will converse

A pretension of blindness except as to color perception, is very difficult to evaluate and when such malingery is suspected, the candidate should be referred to an ophthalmologist for detailed testing. Color blindness when feigned may readily be disproven by the adroit use of colored lenses with appropriate colored test cards a technique which never fails to uncover the simulator. An ingenious trick, recently employed to detect and confound a malingerer who was pretending an extreme presbyopia is worthy of recital. This examinee declared his inability to read anything smaller than No 10 Jaeger Type. The examiner, in sympathetic tone observed that such defect warranted a prompt certificate of disability and thereupon proffered to the examinee a *purported* form for such certification asking him to fill in and sign the same at once. This paper printed in No 2 Jaeger Type had *no* reference to such matters and *the examinee promptly remonstrated that he had been given the wrong form* thereby proving his malingery. Many similar detection methods will occur to the reader and may be utilized ad lib.

Malingeros production of corneal opacity cannot be identified as such unless the examinee can be induced to state a specific date place and cause for the appearance of the condition. A full inquiry through reliable civilian channels may then uncover the falsity of the history recited and permit proof of the perfidy.

Malingeros punctures of the ear drum (or tympanum), when made by an amateur will not occupy the same area of the tympanum as those due to spontaneous rupture nor will they ordinarily be accompanied by the usual signs of a protracted inflammatory process. Their recent origin will usually be obvious and the accompanying abrasions of the external auditory canal will suffice to suggest the use of some mechanical agent by the malingerer.

Extraction of teeth en masse declares itself if recently performed and an inquiry of the dentist alleged to have done such upon ethical grounds should readily elicit condemning evidence. However, in cases wherein the teeth have not been surgically removed but have merely been broken off at the gum line and a claim of accidental injury is made as the explanation thereof it is well to recall that there is scarcely *any* conceivable accidental mechanical trauma which could fracture all the teeth—or any considerable majority of them—at the gum line and yet fail simultaneously to fracture the jaw and also leave definite evidence of gross trauma of the soft tissues of the face chin or neck.

Ulcerations of the nose throat rectum genitalia or skin when chemically or mechanically induced may be detected as such either by



## Malingering

gross appearance or through biopsy or bacteriologic study, and may be substantiated by adroit inquiry after receiving an alleged history of the disability. Such technique of inquiry as to the detailed clinical history applies equally to many other types of simulation, for the layman rarely knows the precise and usual clinical course of even our commoner diseases and defects and so, in his fabrication, will readily betray himself.

Tachycardia and bradycardia, induced by drugs, hypertension resulting from benzedrine sulphate, or hypotension induced by thyroid extract or other agent, can all be identified as malingeringous by detaining the examinee for a protracted period under supervision, so that the effects of the drug may wear off and opportunity for repetition thereof be denied. Occasionally it will prove wise to retain a suspected malingerer overnight to definitely evaluate some alleged disability, as it likewise becomes necessary betimes in the service to prolong the hospitalization of suspected malingerers to achieve a proper determination.

Diarrhœa, or dysenteric symptoms, may readily be produced by the surreptitious self-administration of cathartic agents. Such malingery is not uncommon in army hospitals within the theatre of operations, for the hospital patient finds his situation therein far preferable to the mud and missiles of the combat zone and his food and quarters there more luxurious than in the field. He may therefore endeavor to prolong his sojourn by this, or any other expedient, which seems feasible to him. Thus, while serving as The Laboratory Officer of an Hospital Group in France prior to the Armistice of 1918, wherein we had an entire ward of dysenteric cases of undetermined origin, the assignment of two trained observers (camouflaged as patients) to that ward uncovered the fact that those patients had bribed a night orderly to steal "C.C." pills from the medical supply storehouse and nightly parcel them out to each inmate. The unearthing of the cache of pills, a change of ward personnel, and the prompt evacuation to convalescent camps of the entire patient population followed soon thereafter. *In any case of painless, persistent, afebrile diarrhoea, without discoverable clinico-pathological evidence as to its nature and cause, malingery should be suspected till another reason be substantiated.*

Bronchial inflammation and cough may be criminally induced by the deliberate inhalation of irritant fumes, dusts, atomized liquids, or gases. Here the pathological laboratory will be of vast value by excluding infectious diseases, and prolonged observation of the suspected malingerer under controlled conditions will result in the disappearance of his seemingly serious affliction.

Jaundice may be simulated by the ingestion of large doses of picric



acid or picrates. The yellowish color of the mucous membranes and skin thus induced is, however, not the same as in a true jaundice to an experienced medical examiner, and the detection of picric acid in the stools and urine will identify the malingery.

Rectal fissure is readily produced by mechanical means and may be difficult to label as malingering, unless the recitation of its clinical history condemn the examinee. In one such recent instance, the medical examiner, having been told by a malingerer that the fissure had been present a long time, frightened the examinee into a confession by pretending that he deemed such a long continued state to be probably malignant and would therefore order him transferred immediately to the hospital for surgical operation.

Urethral discharge can readily be produced by the injection of irritative or caustic solutions. Here again, the laboratory survey of smears will be of value as will also the history, and the results of controlled observation. It is of interest to relate that in the First World War, both in the British Army and our own, cases were recorded wherein draftees acquired gonorrhœa to avoid military service, and other instances wherein soldiers overseas did likewise to obtain transfer to hospitals far behind the lines. Such occurrences were responsible, at least in part, for the changes in our Draft Regulations of 1917 to make sufferers from active gonorrhœa eligible to military induction as well as the Regulation which stated that so far as possible, such cases would be retained within their organizations and treated at the regimental infirmary. In one B. E. F. hospital it was found that those patients possessed of a profuse and highly infectious gonorrhœal discharge were selling bits of it to their neighboring bed fellows, at so much per droplet, so the buyers—who were recovering too rapidly to suite their tastes—might with the aid of a toothpick reinnoculate themselves and thus prolong their stay in blighty. Only constant and adequate surveillance over venereal wards can estop such a practice. Such self inoculation as also the deliberate acquirement of the disease from known infected prostitutes is not malingery in its most strict sense since the man actually acquires a serious disease thereby. Yet such conduct, having a malingering intent must be treated as such from a military standpoint and hence be anticipated and strenuously discouraged. Regrettably we must admit there are some men so intent upon malingery to escape military service that they will accept even a severe ailment as a necessary evil in the attainment of their goal.

The immensity of the venereal problem in men of military age became apparent during the First Draft of 1917, and continued to prove



a principal cause of 'days lost from disease' during the progress of our subsequent campaigning. The change in physical standards authorizing the induction of such cases into service which could be rendered effective by treatment, and the official adoption of compulsory prophylaxis, with Courts Martial procedures against those not complying therewith, all sought to remedy such situation.

When the A.E.F. was preparing to return home, a General Order was promulgated prescribing that no soldier with an infectious venereal disease was to be discharged or returned home but would be retained until rendered incapable of spreading the infection in our civilian communities.

Statistics from the present Selective Service Examining, and Army Induction, Boards are not yet available but there is reason to hope that such will prove that the intensive work of the U. S. Public Health Service and of our State and Municipal Health Authorities during the past twenty years have made some impression upon this serious situation. Reports are appearing upon the acquirement of venereal diseases by men now entering the military service. If such infections continue, we may again find revisions necessary in our physical standards and handling of this problem within the services, and may see the reestablishment of special venereal hospitals or treatment camps—possibly again camouflaged by the title of 'Convalescent Battalions.' Much more might profitably be written upon this crucial topic but our main thesis will not permit such digression here.

Various disabilities as to muscles, joints, tendons, and nerves will also be simulated in certain instances but, in most such cases, the history plus an adroit scheme of examination with adequate observation of the examinee while dressing or undressing—and unaware of the surveillance—will reveal the deceit.

There is another class of deceptions, infrequent amongst draft examinees but reasonably frequent amongst experienced soldiers, where, by they seek to attain admission to hospital or confinement to quarters, or prolong such disposition, to avoid some arduous duty, escape combat, or to become lost to a unit or a commander they dislike upon personal grounds or because they deem themselves to be overworked therein. These techniques, practiced by the actually well soldier seek to simulate one or more symptoms of a diseased state, or to produce a seeming lack of full recovery from some disability. Their number and type are both legion and their detection rests largely upon sustained observation under controlled conditions, plus a constant alertness upon the part of the company medical officer and the hospital surgeon. Examples are:



the rubbing of the clinical thermometer against the woolen shirt to elevate its column, or the holding of an hot liquid in the mouth just prior to the testing of the man's mouth temperature, the willful, prolonged retention of urine in the bladder, contortion of 'double joints' to simulate dislocation, the simulation of hoarseness, self induction of vomiting, and many functional derangements of the nervous mechanism of the body. This last named type is one wherein the medical officer possesses little if any, capacity to immediately identify malingery, hence such will continue to plague you throughout your careers. First, there are those who pretend to the possession of headaches, neuralgic pains, cramplike seizures, vertigo, transitory blindness, noises in the ears, epileptiform seizures, fainting spells, etc. Also we may encounter alleged periodic alcoholism, periodic insane symptoms and recurrent migraine in this enumeration. In any such presenting symptom the medical man is indeed embarrassed.

On the one hand, the complainant is far more likely to be a bona fide sufferer and a grave injustice will be done him if he be labelled a "faker." On the other hand any such "racketeering" must not be permitted. I, for one, would deem myself superhuman if I felt certain I could always be sure as to the proper determination thereon, for there is so little as to clinical or laboratory evidence which can be used therein. In all such determinations we must rely upon one or more concomitant signs or symptoms, plus prolonged observation under controlled conditions. Also we may be aided by the recited history of the condition, or by inquiry made of his associates or prior medical attendants—if possible. Lastly, it is important to recall that such periodic, transitory, and trivial ailments may actually be forerunners of some serious constitutional derangement or mental disease which, if then detected, may respond to proper and intensive treatment.

We should briefly mention another class of malingerosus acts committed by some hospital patients to prolong their convalescence which are however, readily detected. These include the willful disturbance of splints or dressings, overdosing with the prescribed medicine to induce a toxæmia, removal of bedclothes to induce a febrile reaction, inebriation with smuggled intoxicants, the induction of comatose states by sedatives or even the cutting of sutures and ligatures. Many such—and more—were witnessed by the author in France.

*It is indeed devastating to recognize, as we must, that all men are not possessed of manhood, and that the 'yellow streak' down the backs of some of our fellows is invisible to the unaided human eye.*

We must not leave the subject of malingering without a considera



tion of two conditions which, in the First World War, our medical examiners and medical officers were not adequately successful in detecting, thereby imposing upon the Veterans' Administration some fifty thousand cases which it carries to this day at huge cost to the national treasury. Obviously, I refer to the Psychoneuroses and to Hysteria. Only prolonged and expert observation will suffice to detect many such cases. In a brief survey by an examiner untrained in psychiatry, many a mild or incipient psychosis will either be overlooked or will be misbranded as malingery and hustled into service to later break down, under the stress of military life, into an obvious and incurable insanity. Yet, many such mild or prodromal cases, if rejected, will continue to death to be no more than 'eccentrics.' If and when such an inductee develops an active psychosis, such man will have a proper claim that his disability is definitely "in line of duty and incident to the military service." The government will therefore have to provide for his care and support his dependents as well. Thus an horrible injustice and damage will result both to the individual, and also to the taxpayers, which no amount of regrets will correct.

The Medical Director of Selective Service fully appreciates the seriousness of this very problem and, in the recently revised and augmented plans for the psychiatric survey of enrollees, has done his utmost—under existing conditions and facilities—to provide opportunity and competent personnel for such determinations. It is to be hoped that the present scheme proves sufficiently effective but there are those—including this author—who choose to delay their judgment. Although the well-developed and active psychotic could scarcely escape detection, it remains to be seen whether, as some authorities apprehend, the many borderline and prodromal conditions will fail of recognition because the period of observation is not yet sufficiently extended nor the skilled examining personnel available in proper quantity. Unless, because of an imminent invasion threat, speed in mobilization be so essential that any and all risks incurred thereby be justified by emergent necessity, it appears to many observers that *the segregation of any and all enrollees with the LEAST suspicion of psychiatric defect for a prolonged observation period would, in the end, be a wise course.*

Some medical men, as well as many laymen, pooh-poo the justified apprehensions as to psychiatric hazards held by those who know their possibilities. Thus, a senior Medical Reserve Colonel recently declared, "A psychiatric specialist is not needed for the identification of psychiatric cases amongst our draftees; any civilian doctor of reasonable experience can promptly and assuredly diagnose any such." Would to God it



were so! (Incidentally in civil life that man is a surgeon)

Our final study concerns the status of Hysteria and its relation to Malingery. Such affliction often presents a most difficult problem in differentiation. Concisely we may state that in hysteria the symptoms possessed or alleged by the complainant are innocently acquired and he truly believes their actuality and seriousness whereas in malingery the symptoms are simulated or intentionally induced. Thus *the one is a mental defect the other a criminal conspiracy*. Furthermore one or more of the definite and well known pathognomonic *signs of hysteria* will be found present at all times in such affliction. Hence we must not brand our examinee as a malingerer until a most careful search has failed to discover any of these signs and we have satisfied ourselves we are not confronting some incipient psychosis. Since the hysteric will be a very poor soldier at best will tend to disturb the morale of his company and continuously impose an undue burden upon the medical service he is to be deemed unfit for field military service. He may, however find proper assignment to some non combatant or industrial activity if and when suitable enactment is accomplished for such disposition of these cases.

Thus we have come to the close of this study of the many phases of malingering. Recalling that it is the duty of the Medical Department of our Military Forces to maintain the greatest possible number of effectives in the combat forces at all times and to return thereto from treatment in the shortest possible interval any and all who can be restored to active military capability—and equally a responsibility to minister adequately to any disabled or ill soldier and not to evacuate him to duty until he be fully fit—we perceive in the topics discussed above many difficulties in the fulfillment of such mission which we must be ever alert to surmount.



## SHAMMING NIGHT-BLINDNESS

By N. BISHOP HARMAN, M.B., F.R.C.S.

Eye tests are of two orders: objective and subjective. We can examine the eye in all its parts with our ophthalmoscopes and other instruments and watch certain reactions to light which are uncontrollable by the mind of the subject. But what the detailed vision of that eye may be we cannot find out except by the voluntary response of the subject. There are occasions when the objective findings and the subjective responses seem to clash. The eyes of a subject on examination may appear quite good in every detail, yet the visual response may be poor. The possibility of checking the visual response by special tests is a problem of interest and present-day importance; it is particularly so as regards seeing in a minimum of light—night vision.

To-day there are many branches of national service that require the citizen, whether a civilian or a member of the Services, to do work that entails ability to see in the dark. Inability to do so means not only danger to the subject but also danger to the community if that subject be truly night-blind or partly so. Is this inability always real or may it be sometimes false? How are we eye men to find out?

### Shamming Bad Day Vision

Something of the same problem arose on occasions during the last war in the examination of men called up for military service. The eyes of a subject under detailed examination were found to be good, but the visual reaction was poor. Then I devised a test which enabled the examiner to check the visual reaction in some measure. This test has since been of much value in examining patients claiming workmen's compensation for eye injury whose visual reaction was much worse than the state of the eye seemed to warrant. The test is as follows:

Two Snellen's test types are fixed one on each surface of the same board. On one side the regular range from 6/60 to 6/6 is fitted. On the other side the types range from 6/36 to 6/5, but the arrangement of these slightly smaller types matches in pattern and in general appearance the normal set of types. The patient is shown No. 1 test type; say he reads three lines:  $V=6/24$ . Now No. 2 test type is exposed; if he again reads three lines his vision is really 6/18 and he is convicted of inconsistency and suspected of shamming deficiency. The test is easy to apply and has proved to be very useful.



### Shamming Bad Night Vision

Checking suspected shamming of bad night vision is a much more difficult problem. If there is found in the eyes of the subject density or opacity of the media, or very small pupils that do not dilate, or defect of the fundus oculi then the deficiency is likely to be genuine. High errors of refraction and the need for thick lenses will also make it genuine. But in some cases there is good daylight vision, no discernible sign of defect on the objective examination of the eyes, and no general defect of health or nourishment to explain the poor night vision reaction. There may be as complete an absence of any ocular evidence in confirmation of the night vision defect as there is of anomalies or lack of colour vision.

By applying the experience with the daylight test described above it is possible so to vary the use of the disk spotting test as to make it a check upon the reaction of the subject. This can be done in two ways (1) varying the light, (2) altering the size of the disks on the test.

1 *Varying the Light*—The candle box enclosing the standard candle has a projection tube through which the light passes to the white disks on the test board. A cap, like a pill box lid, can be made with its flat surface of semi-transparent grease proof paper, the density of this film can be chosen so that it cuts off half the candle light. Or the light may be increased instead of diminished, if a hand torch with a sliding or adjustable reflector can be held alongside the candle box the adjustment can be made so that the torch light reinforces the candle light and increases it three or four times.

2 *Altered Disk Sizes*—The size of the disks in the test board can be changed. The normal pattern disks are  $\frac{1}{2}$  inch in diameter and  $\frac{1}{8}$  inch in separation from each other. In the test board (as made by Theodore Hamblin Ltd) there is space enough on the velvet surface of the base board between disk groups 4 and 5 to allow to be pasted to it another set of disks, four in number, each of  $\frac{3}{4}$  inch in diameter, and separated by  $\frac{1}{4}$  inch. Thus the size and distinction of the disks in the candle light can be suddenly altered by turning the test cover during the examination.

There are then three ways in which the test may be made more difficult or more easy. If the subject with bad night vision is genuine in his disability he will show this in his response to the variation of the test. When the light is less his vision will be worse, when the light is brighter he will see much better and at a greater distance. So also will he see somewhat better when he is shown the larger disks. For example, a



subject whose response to the regular test was only 2.5 metres was tested this way. (The average response of normal subjects is at 5 metres.) After a full dark adaptation the varied tests were made. He could only count the disks in the reduced light at 1 metre; he could count them easily at 6 metres with the added light; he could count the larger disks in the usual fractional candle-light at 3.25 metres. There was thus reasonable consistency in the reactions of this subject to light variations, so the night-vision defect was considered to be real. In making these variations of the test in suspected cases it is desirable to have an assistant to help the examiner manipulate the test. The examiner should stand with the subject. Between each grade or alteration of the test the eyes of the subject should be covered, so that there will be no actual observation of the changing of the conditions of the test.

### **Conclusion**

Applying tests to check subjective vision reactions requires much nous on the part of the examiner. It is a trial of wit against wit. The "cutest" one of the pair, examiner and examinee, will win the trial, but that is the normal reaction of a medical practitioner; he is always faced with problems in diagnosis and the interpretation of symptoms that demand acuteness of judgment.



## THE PSYCHOPATH IN THE ARMED FORCES

By WILLIAM H. DUNN, M.D.

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It is the purpose of this survey to examine some of the problems which face the Selective Service Examining Boards and the military medical officers in dealing with persons who are classed as psychopaths, psychopathic personalities constitutional psychopathic inferiors or under any of the other ten terms applied to this rather heterogeneous group of socially maladjusted persons. These persons have been characterized as making up one of the most disruptive elements in society. This holds true for peacetime and their potentialities for trouble making are considerably enhanced in a time of national emergency whether they are in the armed forces or still at large in the civilian population.

Before embarking on a discussion of the psychopath in his reaction to military life it will be necessary to make some general remarks about this type of person. This seems necessary because of the degree of confusion which still exists about this reaction. There is still considerable conflict of opinion regarding the etiology, much obscurity concerning the psychopathology and even a considerable vagueness in defining the boundaries of the group.

We may say that the psychopath is not necessarily psychotic or ordinarily suffering from any serious distortion of reality though in some cases psychotic episodes occur. The psychopath is not necessarily neurotic though under certain circumstances and particularly in wartime such a person may show neurotic and often hysterical symptoms. But ordinarily the psychopath shows none of the usual neurotic picture for which we are accustomed to look. He tends to act out rather than to form neurotic symptoms. Furthermore this acting out very frequently produces suffering or unhappiness for those in his environment with very little conflict guilt feeling or suffering for himself. This is very much in contrast to the usual neurotic's reaction. The psychopath may be feeble minded but this is not necessarily or usually the case. One may find chronic alcoholics and drug addicts criminals and delinquents and sexual deviates among the psychopaths but once more this is not necessarily the case. In our opinion one of the best criteria for classifying people within this group lies in the study of social behavior. We are dealing with those who dramatize primitive impulses into real action<sup>1</sup> with the consequent development of chronically deviated and pathological social behavior.<sup>2</sup> They manifest this pattern of behavior



from childhood or early youth and while they may develop physically and intellectually in an entirely adequate fashion, a particular type of emotional immaturity persists. This is represented by the tendency to act out and by the strong drive to seek for immediate satisfactions and pleasures without regard to the future. In the drive for this immediate satisfaction, the psychopath shows little regard for his family, friends or even his own welfare as measured by future gains from deferring his impulsive action. One can agree to Levine's<sup>2</sup> definition of the psychopath as a person who is not necessarily psychotic, neurotic or feeble-minded, who attempts to solve his environmental and internal conflicts by preserving the primacy of short term values and acting out. If this type of reaction is to be given the dignity of classification alongside the other great groups of mental disorder, it attains that position on the basis of this identifying quality of chronic and persistent social maladjustment.<sup>3</sup>

It has been widely assumed that inborn constitutional factors play an important role in these reactions. To a considerable degree, the evidence for this is circumstantial.<sup>3</sup> Certainly we find psychopaths with obvious evidence of constitutional organic inferiority often accompanied by mental defect. But this group would be very much in the minority. The majority will show no marked physical anomalies or intellectual defect. Many are rather superior physical specimens and of good intelligence. In many cases, one may find a history of psychopathic family traits. But even here, as in all personality disorders, it is often difficult to distinguish between hereditary factors and the influence of a psychopathic personality of the previous generation on the child who later develops in this direction.<sup>4</sup> We find a considerable percentage of cases in which there seems rather a good family history and obvious evidence in the person's behavior pattern of his reaction to environmental pressures which have begun to exert their effect in a very early age period. Constitutional factors are certainly important but they are not striking enough in many cases to enable one to make an easy diagnosis on that basis.

Earlier, we presented some of the criteria which justify placing the psychopath in a separate classification. Now we should like to present a somewhat more descriptive picture of the psychological structure. Visher<sup>5</sup> presents such material in his tentative definition. He comments on the psychopath's defects in will and inhibition; his lowered threshold for stimuli; his egoism, impulsiveness, poor judgment, incapacity to conform to ethical or social standards; inability to adjust to, or profit by, experience. For a further description of the psychopath in relation



to his environment, we may turn to Karpman<sup>6</sup> He points out their hardness even in childhood, which is so much in contrast to the sensitivity of the neurotic child the resistiveness to training and discipline, their difficulties in school in accepting teaching and in conduct, their early tendency toward emotional instability and delinquency, their bullying cruel and tricky attitudes toward playmates From their early years they are unable to defer present pleasures for future gains and in satisfying their immediate desires almost any means justify the end no matter how unscrupulous it may be or how much suffering is entailed for relatives or friends Consequently, they are in constant conflict with their environment but never learn to profit by experience They seem unable to exercise foresight in avoiding the difficulty from which they have just been rescued And they are almost always in need of rescue from some unpleasant situation but they are without sentiment or gratitude and are apt to repay kindness with a mean action As they are swept by gusts of emotion and beset by their infantile primitive instinctual drives they cannot persevere in working toward a goal This makes for poorly defined and changing ambitions with frequent shifts in employment Furthermore they are so stubborn and unyielding to situations that in civil life, they frequently come into conflict with superiors over petty matters and are discharged or leave in high dudgeon But with all this precariousness of employment, they frequently live well and well beyond their means They are glib and convincing talkers who find it easy to borrow or swindle Among them, one may find criminals of all types In our general population, they are represented among the pathological liars the swindlers, the gamblers the tramps the eccentric the alcoholics, and drug addicts

Finally, before proceeding to a discussion of the psychopath in the military milieu we should make some attempt at classification of this type into sub groups This is a very baffling problem as evidenced by the various studies condensed in the survey made by Partridge<sup>3</sup> According to him Kraepelin lists some seven sub groups, Schneider gives ten well defined types and other writers may be found who give even more For the purpose of this study and for purposes of brevity, we shall use Partridge's work plan of making three somewhat loosely organized sub groups which incorporate the many types reported by the large group of writers whose work he studied His first group would be the inadequate which would include the insecure, the depressive, the weak willed and the asthenic Partridge<sup>3</sup> points out that many persons included here might not be too securely placed as other observers might class some of these cases with the neurotics or in such categories of the



major psychoses as the simple schizophrenias. His second group would be made up of the emotionally unstable and egocentric and would include the contentious, paranoid, explosive, excitable and aggressive psychopaths. Finally, in the third group, he would place those who are most flagrantly anti-social—the liars, swindlers, vagabonds and sexual deviates.

From the point-of-view of military psychiatry, the group is well worth review. In the World War, of approximately 72,000 neuro-psychiatric cases returned to civilian life from our forces up until 1 May 1919—9 per cent were classed as psychopaths. Nearly all neuro-psychiatric cases evacuated to the United States from the American Expeditionary Force in France passed through the hospitals at Savenay. In this hospital group 10 per cent were psychopaths.<sup>7</sup> Baillie made a report recently on 200 neurological and psychiatric admissions from the Canadian Army Service Forces of the present war. In this group of consecutive admissions, seventy cases were diagnosed as constitutional psychopathic inferiority—that is 35 per cent of the number. Alcohol and malingering contributed another nine cases.<sup>8</sup> In a recent newspaper article,<sup>9</sup> Cooley of the Veterans' Bureau was quoted as critical of draft boards in the last war which, he said, swept all the "ne'er-do-wells" into the Army on the theory it would "make men out of them." His criticism would seem justified by the figures quoted. But it is not entirely a matter of local authorities following the rather common cultural attitude that social deviations may be successfully controlled merely by the imposition of sufficiently rigid discipline. There is a considerable difficulty in detecting these registrants under the conditions necessarily existent in the Selective Service examination. A more generous time allowance for the examination would not completely solve the problem. Difficulty arises particularly from the fact that the psychopath tends to act out his conflicts rather than to express them in symptoms as the neurotic does. For diagnosis of these states an adequate social history is imperative. The psychopath is not apt to reveal his difficulties with the environment voluntarily. The possibility of obtaining an objective account of his social history is limited.

In order to be more convincing regarding the importance of detection of the psychopaths in these examinations it would be well now to review some of the literature on their conduct under military discipline. Karpman<sup>6</sup> comments on the strong appeal which the Army and Navy service makes to the psychopath and on their inability to stand the discipline with the consequence that they come in conflict with Army regulations or else desert on slight provocation. Bailey<sup>10</sup> speaks of the



psychopaths as frequently making a first impression of superficial brilliance, enthusiasm and perhaps showing some transitory claim to leadership, but soon demonstrating his instability and changeableness. In his opinion, the majority are eventually disloyal to any organization and, by reason of their suggestibility, may easily become tools of propagandists for spreading seditious doctrines or the commission of acts in defiance of law and order. If their potentialities are not always so serious as this, it must be said that because of their social maladjustment, they are unsuitable for work in cooperation with their fellow soldiers and will be in constant trouble in the Army. Gregory<sup>11</sup> makes essentially the same estimate of this group in commenting on the baffling problem that they, and other borderline states, offered in the cantonments during the last war. They constitute a greater menace to the military organization by lowering the efficiency and impairing the general morale than do the obviously diseased types which are readily recognized and without great difficulty eliminated. They are a constant source of annoyance and trouble to the officers, forming the larger number of the absentees, the discontented, the inefficient, the inmates of the guard house and the frequenters of the regimental infirmary. In McPherson's<sup>12</sup> opinion, the examiners should have been less conservative during the last war in the rejection or discharge of persons so unequal to the demands of the Army as were the psychopaths. In a bulletin issued by the Surgeon General's Office,<sup>13</sup> one finds further comment on the trouble breeding activities of the psychopath in the service. They cannot cope with the world except in their own peculiar way. They are considered useless in the regular service as they are unable to adjust themselves to discipline. They are persistently insubordinate, excessive in the use of, and intolerant to, alcohol, likely to be addicted to sexual perversions. This type is liable to develop a psychosis when they are unable to escape conditions to which they cannot adjust themselves.

The above comments deal with the general reaction of such soldiers in cantonments. Sanger Brown<sup>9</sup> has this to say about the psychopaths evacuated to Savenay from units of the American Expeditionary Force in France. 'While not suffering from frank mental disease, nevertheless they were in a mental condition sufficiently abnormal to bring them into serious conflict with those about them. These cases did not differ materially from those seen in civilian life but showed such additional features as might be expected to develop under a military regime. Patients of this kind might make fair progress in civil life where they could change their occupation and surroundings but in the military service this was impossible and they broke down nervously as a result



Indeed, they frequently suffered from temporary mental disorders."

Various European authors might be cited further to substantiate our impression of the general undesirability of the psychopath in the military service. Bonhoeffer<sup>14</sup> states that while the war may have had a good effect on a small number of psychopaths, it was for the majority the occasion for the development of a more intensive psychopathic reaction. For future wars, he felt the great problem for the psychiatrists in military service would arise in the handling of these persons. Stier<sup>15</sup> is another German writer who, on the basis of his war experience, stresses the problem of the psychopath. Wolter<sup>16</sup> comments on the easy recognition of most mental disorders in the constricted living arrangements of troops in cantonments, but admits to difficulty in detection and handling of the psychopath. He states that the problem cannot be stressed too much and that it must be solved for it has great significance for the fate of the country in war. Baeyer<sup>17</sup> comments in a similar vein. Among the Swiss authors, Hans Maier<sup>18</sup> speaks of the frequency with which the psychopath will be drawn into military service; but says that service cannot serve as an educational institution for such persons. Nelken,<sup>19</sup> of the Polish Army, demands the elimination of all psychopaths in peacetime and great care in their selection during mobilization for war. Gauthier<sup>20</sup> and Fribourg-Blanc<sup>21</sup> of the French Army may be numbered among the writers who place the psychopaths high on the list of problems for the military psychiatrist. The above should serve to demonstrate that the psychopath is considered an undesirable in the armed forces. Nearly all of these writers advocate their elimination from the ranks in peacetime.

The psychopaths who enter the military milieu with its demand for "absolute" obedience, order, performance and cooperative relationships find themselves in a new social environment which will tend to exacerbate even the latent psychopathic tendencies which have not been aroused in the more flexible civilian life. They find themselves incapable of meeting the demands of this new environment and may develop tendencies such as shirking, evasion, obstinacy, personal resistance, open disobedience, unreliability, treacherousness, flight into illness, desertion or suicidal attempts. The line officer often finds them among the soldiers who never have their equipment in good order; who try to evade fatigue details; who cheat in order to satisfy bodily needs; and on whom praise, blame or punishment have little effect. Summary court-martials and guardhouse punishments stud their service records. The line officer is exasperated and annoyed but if he consults the regimental surgeon, all too frequently he arouses no interest. The psychopaths continue their



wayward course unless some punishment provokes an explosive outburst or they desert—often to turn up later to accept harsh punishment for what may have originally been a minor military delinquency.

Baeyer studied a small group of deserters psychiatrically and found 73 per cent were psychopaths. Osipov<sup>7</sup> found that 10 per cent of the military prisoners in the punishment battalions of the Russian Army were psychopaths. Baillie<sup>8</sup> states the psychopaths in the Canadian Forces presented a major disciplinary problem. Others who find the discipline intolerable make suicidal attempts. Fribourg Blanc<sup>21</sup> comments on the frequency of suicide among the impulsive excitable psychopaths. Heidenhain<sup>22</sup> found that over half of the military suicides were psychopaths. Scouras<sup>9</sup> also reports on the frequency of the suicidal attempts among this group. There has already been comment regarding the real possibility of a Ganser Syndrome or of a psychotic break if they are not otherwise able to escape.

Under war conditions their potentialities for trouble making may pass over into the dangerous stage. One hears occasionally that the psychopath makes a good soldier. In this review of the literature such comments were rare. Hoffman, Kittel<sup>1</sup> and Kluge<sup>23</sup> state that the emotionally unstable psychopaths who may be explosive and excitable but who have a predominantly cheerful mood may be useful under skillful and understanding leadership as shock troops and for raids. But they qualify this by saying their unreliability and capriciousness must never be underestimated. Gauthier<sup>6</sup> stresses this in speaking of French colonial troops. He emphasizes the unsteadiness of their will and instinctual forces—their overly excitable affectivity which may bring them up for court martial on one occasion and for decoration at the next. Their behavior may be heroic at one time and so panicky as to be dangerous at another. He says one can never trust them without being deceived as to their true worth. In addition to this undependability slight stimulus may send them into an euphoria and consequent conflict with authority and their superiors. Colonel William C. Porter<sup>10</sup> of the American Army was quoted recently about this same type of psychopath—the aggressive psychopath of the kind that could go over the top, clean up a situation and win a medal but did not make a good soldier because he could not take retreat or inactivity.

Other members of the emotionally unstable group—the contentious and paranoid—show an enduring dissatisfaction and irritability. They are often on sick call, are unsocial, meet discipline by refusal to obey and threats against superiors, often become military criminals. They are a danger to the morale and discipline of their fellow soldiers by



spreading dissatisfaction and by their fault-finding. When in liquor they are especially troublesome.

The weak-willed offer more of a problem. They are extremely impressionable and changeable. In the early stages of their enlistment, they may get on well but they are soon trapped by their own character defects into carelessness, negligence, untrustworthiness, lies and deceptions, self-promotions and self-decorations—into going absent without leave. They and the contentious, paranoid group are easy marks for the designing propagandists mentioned by Bailey.

The emotionally unstable group in its entirety and the highly impressionable weak-willed psychopaths may be very much of a danger. The explosive and excitable may by impulsive dare-deviltry, carelessness, or simply by their resentment of restriction draw fire that will endanger their comrades or cause the loss, by their undisciplined behavior, of valuable military equipment. At other times, this same impressionability or excitability may cause them to produce illusions or hallucinations of dangers with consequences that may actually be dangerous for their fellow-soldiers. This may be particularly true while they are out in listening posts—during raids. These same traits make it extremely difficult for them to stand long stretches of trench or position warfare. At times the monotony may drive them into extraordinary carelessness; at others they may become so unable to bear the situation that they attempt desertion in the face of the enemy or make suicidal attempts.

These psychopaths are also of particular importance in the type of warfare that is now being waged. They have a great capacity for spreading psychic infection among both troops and civilians. Entire detachments can fall into the trap of panic set by their dissemination of dangerous suggestions growing out of their impressionability. In the state of psychic tension which the enemy now tries to produce among the opposing armies and civil population these persons serve a most useful purpose. The pathological liars and swindlers are also apt to play an important role in the general state of credulity and lack of critical judgment which the enemy tries so hard to produce before pressing home their attack. They may be almost as effective as enemy agents and, of course, may become such though probably not very dependable ones.

The inadequate group, and particularly the depressive persons, make less difficulty. They do not adjust at all well to the service, but they do fulfill their duties even though with hesitation and indecision. In these depressives, desertion and suicidal attempts are common.

Asthenic psychopaths cannot stand soldiering. They are emotionally



weak overly sensitive tender fail physically become hypochondriacal and many simulate illness This is a description by Heidenhain<sup>25</sup> of individuals in the German Army whom we should probably class as neurasthenics But we do see the spiritless indolent psychopaths who have no sustained interests or desires who are unclean and indifferent and on whom reprimands and punishment have no effect They are apt to desert and are apt later to develop into simple schizophrenics

There can be no argument about the desirability of early detection of the psychopath whatever the decision of the military authorities regarding their acceptance into the service In the Selective Service System it will be extremely difficult for the psychiatrist to diagnose such persons It will be difficult under the time limitations necessarily imposed but even more because of the meagerness and source of the social history The psychopath is not an individual who is disposed to frankness and honesty about his past history of difficulties with his environment In fact he will be inclined to gloss over unpleasant but important episodes Furthermore the psychopath tends to act out his conflicts and frequently will not show evidence of symptoms that are often helpful to the examiner in diagnosing the neuroses and psychoses There should be no great problem with those showing organic inferiority with physical stigmata or mental defect The physical signs will be obvious and those with mental defect are soon discovered under our system and either suitably placed or discharged for military ineptness But the psychopath whom we have tried to present in this article as a problem is frequently a fine physical specimen with a good intelligence as uncovered by ordinary test procedures who feels that the army offers various desirable possibilities—economic independence from families escape from their repeated failures in civil life and the satisfaction of a desire to play soldier Consequently they try for and too often succeed in making a favorable first impression The most important single diagnostic factor is the social history as given by an objective observer In the smaller communities the members of the examining boards may know many of the candidates and can be of great help to the psychiatrist by supplying such information if they are made aware that the psychopath is not going to be able to solve his own problem and his family's under army discipline In the larger cities this information is apt to be lacking in the members of the board unless prisons parole boards psychiatric—hospital and clinic—organizations and social service agencies furnish lists of the men of draft age who are or have been on their rolls There would be resistance to submitting case reports but it would be a great help to the examiners if they merely knew of the candidates



who had had such contacts—and could then give them some special consideration as suspects. However, one may anticipate much resistance to this type of request. For the average case, one will probably have to depend chiefly on the family history of psychopathic traits or psychiatric conditions if that is available. The psychopath may be guarded in giving such information but will be free about giving his school and occupational history which may offer the clue that will lead to further investigation. A history of repeated accidents or injuries would be suggestive as has been recently demonstrated by Dunbar<sup>30</sup> and her co-workers in their study of the personality makeup in fracture cases. These leads are meagre but may well be all that will offer except for the possible behavior of these impulsive, undisciplined persons under the mild restrictions that would exist during a lengthy examination.

In times of peace there seems to be little disagreement about their undesirability in the armed forces. The most important reason for eliminating them, before induction would be to prevent their reaching the cantonment—breaking down within a few weeks—and then be in a position after discharge to collect some sort of compensation or government hospital care for years. It is not uncommon for patients to come into psychiatric clinics today who have collected compensation for neuropsychiatric disability for all the years since the last war. On taking the history, one finds they never had any more active service than the depot brigade and that for only a few weeks or months. It may be that there are today regulations which will prevent this sort of a situation. If so, the present system used in the Navy and apparently now in Army cantonments could be effective. In a recent article on the Navy, Dravo<sup>31</sup> described that system of holding recruits in detention units for a period of several weeks after induction. The abrupt shift in environment; the restriction of freedom to move about; the discipline serves to reveal the psychopath most effectively. They tend according to Dravo to develop functional disorders, including hysterical seizures, enuresis, and various other neurotic manifestations or malingering. Occasionally, there is a suicidal attempt or a more severe mental break. In any case, this environmental pressure does bring out the psychopathy and brings the man to the attention of the psychiatrist. Almost all psychopaths have to be eliminated from service. Dravo gives discussion of the methods.

It is possible some psychopaths may last through their detention period and break out into their behavior patterns later. For the detection of these cases, it would seem that the regimental medical officers must be more aware of the implications of such behavior than was true in



the last war—and much more ready to accept the complaints of the line officers and non-commissioned officers in this regard. It would seem very much worthwhile to make psychiatric surveys of those who appear on more than one occasion before a summary court-martial and on all of those whose offense brings them before a general court.

Most European writers would be inclined, during wartime, to hold the psychopath under military control. Bonhoeffer, Stier, Nelken, and others, all believe they should not be returned to civilian life due to their potentialities for undermining morale and breeding panic. Under the conditions of present-day warfare, this would seem particularly wise. The Europeans also recommended that they be held in labor battalions for work behind the lines rather than with combat units and with the more dangerous element in prison camps. Inadvertently this happened in the last war as many psychopaths did gravitate either to hospital or into disciplinary battalions as military prisoners. A recent article by Schmitt-Halin<sup>22</sup> would suggest that is the policy of the German Army today. Baillie<sup>9</sup> states "One recognizes that in military life, especially in these days of mechanization, there is very little use for these men in the general scheme of things. However, one does believe that some use could be made of them." He considers them unfit for combat service but found about half of the group on which he reported who could work on the line of communication.

The military psychiatrist is offered a great responsibility and a great opportunity if these men are held in the Army. It is possible that with the assistance of the psychologists and newer characterological tests, a more accurate survey of such individuals may be made that would permit of their more effective utilization. In any case, an opportunity would present for a study of these troublesome people which has not been effectively carried out so far and might teach us something about their adjustment in later civil life.

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## THE CARDIOVASCULAR EXAMINATION OF THE ARMY RECRUIT

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It is obvious to anyone who has followed the course of the present war that a high degree of stamina is vital to the modern soldier, perhaps even more so than ever before. It is necessary, therefore, to adhere to the strictest standards when deciding whether or not a man should be classified as 'fit for general military service'. In reaching a conclusion one must visualize as nearly as one may from this present distance the rigors of modern warfare, and furthermore, the examiner must bear in mind the question of possible future compensation arising from a certificate of disability discharge.

Criteria that might rightly be applied to civilian life may not be proper for the modern military regime, and it should be constantly remembered that the army of today functions more than ever as a unit and that even the temporary disability of one man may be of grave import to the unit as a whole. Moreover, it is probably incorrect to assume that because a man has been "athletic" in civil life he will necessarily be able to endure the hardships of an extended and concentrated campaign under modern conditions. One professional athlete who had successfully participated in his chosen vocation in October, 1940, was properly rejected by the United States Army for gross physical defects a month later. In this respect, Paragraph 1-b in A. R. (Army Regulations) 40-105 is worth recalling: candidates for commissions in the organized reserves "must be free from any defect or pathological condition which would interfere with the performance of the duty expected of them in the Army, or which would, as a result of service, be especially liable to undergo progressive change or to become the basis for a claim against the Government in the event of call to active service."

This discussion is concerned only with the cardiovascular system of the recruit, and much has been learned in this respect in the past twenty five years. The standards relative to other body systems should be quite as exacting.

Up to May, 1918, "heart disease" ranked third in the list of causes of discharge from the British Army and the Royal Navy,<sup>1</sup> yet in 1938, diseases of the circulatory system accounted for but one tenth of the annual death rate in the United States Army.<sup>2</sup> It is problematical



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whether this major difference is due to increased attention to the cardiovascular system, to the reduction of the incidence in certain diseases leading to cardiovascular disorders or to the fact that from 1914 to 1918 the British forces were actually at war. It is likely that all these factors are involved. On the other hand, it is interesting that only 0.8 per cent of 37,000 men at Camp Devens up to May, 1918, were rejected for cardiovascular disorders,<sup>2</sup> and that during World War I approximately 0.5 per cent of all men drafted and sent to military camps were rejected for cardiovascular defects.<sup>3</sup> It should be especially noted that neither of these statistical analyses includes those men rejected by their local draft boards. The figures cited correspond more closely to those of the present induction centers (now designated as examining centers). The Metropolitan Life Insurance Company rejects as "ineligible for standard life insurance" approximately 2 per cent of all applicants below the age of thirty-five. Preliminary figures show that, in 1941, slightly over 3 per cent of all men have been rejected for cardiovascular disease by their local examining boards.<sup>4 5</sup>

The various induction centers of the United States Army are guided in their selection of men by regulations covered in M. R. (Mobilization Regulations) 1-9. At these centers, only men are examined who have been passed as physically fit for general military service by their local selective-service boards, together with those men applying for regular enlistment in the Army and a certain number of aviation cadets who have been, or will be, examined further by a flight surgeon.

Under Paragraph 55 of M. R. 1-9, it is apparent that to be placed without question in Class 1-A (general and unlimited military service) a man must have a cardiovascular apparatus free of all but the most trivial deviations from the strict normal. The apex impulse must be within the midclavicular line, and no thrills or "important murmurs" may be present. The pulse rate must be under 100 and over 50. No cardiac arrhythmias are allowed other than sinus inequality and infrequent extrasystoles. More than transitory hypertension patently due to excitement is disqualifying. Neurocirculatory asthenia, unless mild, is likewise a cause for rejection. All this is as it should be, and it must be especially noted that, at present, the induction centers—in contrast to the local examining boards—either flatly accept or reject a man. The Army does not now consider Class 1-B (limited service), except under very special circumstances requiring a waiver from the War Department. In this respect, the induction centers differ from the local examining and advisory boards, which may, at their discretion, place a man in Class 1-A, 1-B or 4.



However according to the same regulations, it is incumbent on examining physicians to accept for service men with "accidental functional murmurs or with other findings that do not indicate disease or impair the selectee's ability to undergo severe bodily exertion, and to exclude those with defects however innocent, appearing at the time of examination that would interfere with their activities (Paragraph 60, M R 19)

As a result of the experience of eleven months at the Boston Induction Center Fourth Recruiting District, and with the help of several cardiovascular experts, certain conclusions—subject to subsequent change—have been drawn. It seems worth while to bring these conclusions to general attention for future reference and, perhaps, amendment

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It is obvious that all recruits with organic heart disease of whatever nature should be summarily rejected (Paragraph 57, M R 1-9)

No recruit should be accepted if he has a diastolic murmur at either the apex or the base

It is probably best that all recruits having an undoubted history of rheumatic fever should be rejected, even if there is no demonstrable cardiac damage at the time of examination. The possibility of recurrent rheumatic disease and of late development of valvular or myocardial disease must be considered. It is obvious that certain men may wittingly and with malice aforethought feign such a history. In such cases, documentary evidence from the patient's physician or hospital records is of the greatest value. On the other hand, men may knowingly conceal their past disease, although there are severe penalties for so doing. In such cases, a history of repeated nosebleeds, continued unexplained fever or chorea (infrequently associated by recruits with rheumatic fever) may be of some help. Recently, a man was accepted by the internist only to be rejected by the neurologist, who elicited an unquestionable past history of chorea of many weeks duration. In doubtful cases an electrocardiogram and six foot film of the heart should be taken before final acceptance or rejection.

All applicants showing arteriosclerosis or arteriolar sclerosis should be rejected.

Any gross inequality of the pulse should be a cause of rejection. It is commonly taught that excitement, sleeplessness, alcoholic excesses and the like predispose to extrasystoles, yet I have been surprised to find how rare this irregularity is in recruits or selectees even though many of them have been subjected to one or all of the supposed inciting causes.



This paradoxical experience should serve to emphasize the importance of any notable arrhythmia.

The question of the significance of systolic murmurs is as difficult at induction centers as in civil life. It seems reasonable that the presence of a low-pitched, soft, systolic murmur localized at the pulmonary-valve area, or even heard at the apex, unaccompanied by other cardiac abnormalities and not preceded by a history of rheumatic fever or chorea, may be regarded as of no consequence, especially if the man appears otherwise healthy and robust. A mitral systolic murmur accompanied by an increased pulmonic second sound, slight cardiac enlargement and a history of rheumatic fever is, on the other hand, obviously a cause for rejection. Between these two extremes lie many cases. There are competent cardiologists who believe that a systolic murmur at the apex, even though loud and transmitted to the axilla, if unaccompanied by other signs should be regarded as consistent with good health. This may well be true in civil life; it is probably not true in war, and there is some evidence that even in civil life such a murmur cannot be dismissed too lightly.<sup>9, 7</sup> In this respect, the opinions of Boume<sup>8</sup> are of interest. Discussing the examinations of the heart in British recruits, this author says: "If a systolic murmur is entirely absent in the erect position, it is unlikely to be organic. If present only in the erect position, it is almost certainly functional in type. If absent during phases of respiration, it is unlikely to be organic." Essentially the same views are expressed by Parkinson.<sup>9</sup> It is undoubtedly wise to reject any man who shows a loud, harsh, systolic murmur transmitted to the axilla *even though such a murmur is unaccompanied by other pathologic signs.* That this dictum is contrary to the teachings of some is fully recognized. The opinion has not been hastily formed.

Mitral "presystolic" murmurs are also difficult to appraise. The truly presystolic murmur—especially if of the rough, crescendo type, accompanied by a loud snapping first sound and increased by exercise—should be regarded as a cause for rejection. In many cases, however, a selectee or recruit may come to the induction center with a pronounced tachycardia, and in these men one not infrequently hears what seems to be a presystolic murmur. It is in actuality more a grating quality to the first sound in an over-active heart, and it almost always disappears if the man lies down for half an hour. Such a murmur may be disregarded if no other abnormalities are present and if the past history is negative.

Men with pulse rates of 100 or over should be rejected unless the tachycardia subsides with adequate rest. It is essential to distinguish between the tachycardia caused by an unstable and nervous temperament



and that patently due to excitement, temporary nervousness or lack of sleep. The latter type will almost invariably subside after half an hour's or an hour's recumbency with the added distraction of watching others undergo their examinations. It is obvious that acute infections may similarly be accompanied by tachycardia, usually, the site and nature of the infection can easily be found. Tachycardia that does not subside during the day of examination should probably be regarded as evidence of an unstable cardiovascular or nervous system and should therefore be considered a cause for rejection: a man on active service can scarcely demand a few days' rest. If the tachycardia is the only abnormality, the examiner may be justified, in rare cases, in asking the man to return on another day for a second examination. Initial rates of 130 or over very seldom come down to normal. Marked tachycardia may follow the use of certain drugs either for therapeutic purposes or because the man being examined is a malingerer. This possibility should always be borne in mind, although not many such cases have been recognized at the Boston Induction Center.

The question of blood pressure is a most difficult one. The regulations (M. R. 19) state that men should be rejected who have a persistent blood pressure at rest above 150 millimeters systolic or above 90 diastolic, unless in the opinion of the medical examiner the increased blood pressure is due to psychic reaction and not secondary to renal or other systemic disease. When the first inductions took place in Boston in November, 1940, it was the opinion of one cardiovascular expert that for all practical purposes, blood pressure readings could be dispensed with, since the number of true hypertensive patients in this age group would be negligible. This view has gradually been modified, and blood pressures are now taken on all men with initial pulse rates of over 100 on all men showing more than a slightest possible trace of albumin and on all obese applicants. If the blood pressure is more than 150 systolic or 90 diastolic, the recruit is rested until either the pressures have become normal or it is apparent that they will remain elevated during the day of examination. The original practice of having men return on subsequent days for further check-ups has been discarded. If rest for three days is needed to attain normal readings, it is probable that the applicant has either essential high blood pressure or neuro-circulatory asthenia. In this area, we have not, so far as we are aware, encountered blood pressures elevated because of drug addiction. In other parts of the country, such falsely elevated blood pressures are not uncommon. The possibility of malingering should always be borne in mind. Adopting a long range and conservative view, and influenced



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by the work of Hines,<sup>10</sup> we now reject men whose systolic blood pressures remain over 150 and whose diastolic pressures remain over 90 during the day of examination. Grossly elevated blood pressures frequently fall to strictly normal limits within an hour. Such variations from the normal may probably be disregarded.

Neurocirculatory asthenia is, according to Bourne,<sup>8</sup> the "commonest cause of cardiovascular breakdown under the strain of active service." The subjects are usually high strung, repressed, fastidious in their habits and subject to palpitation, precordial distress, abnormal sweating and dyspnea or dizziness on exertion. Occasionally, the dyspnea may be extreme. There is usually an associated tachycardia. The blood pressure, particularly the systolic, tends to be elevated but variable. Sighing and yawning are common stigmas. This condition, which is probably of nervous rather than of cardiac origin, calls for summary rejection unless it is very mild. It should be noted that the syndrome is rather closely simulated in men who have, the night before examination, been on an alcoholic debauch.

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When all is said and done, it must be admitted that a man is no stronger than his cardiovascular system, and that this system may be

**TABLE 1**

Rejections Due to Cardiovascular Abnormalities in 1940 (8708 Men)	
<i>Cause of Rejection</i>	<i>No. Rejected</i>
Essential hypertension .....	39
Rheumatic heart disease .....	15
Mitral stenosis .....	4
Aortic regurgitation .....	2
Mitral regurgitation .....	1
Unspecified .....	8
Neurocirculatory asthenia .....	6
Organic heart disease, type unspecified .....	4
Tachycardia .....	4
Hypertensive heart disease .....	1
Auricular fibrillation .....	1
	<hr/>
Total rejections for cardiovascular disease .....	70
Percentage of total examinations .....	0.8
Percentage of total rejections .....	4.9

subjected to very severe strain over an indefinitely long period. We are increasingly convinced that the cardiovascular standards for admission to the United States Army should be of the strictest sort.

Tables 1 and 2, which are derived from the work sheets of the Boston Induction Center, Fourth Recruiting District, reflect this increasing con-



servatism and indicate in a general way the causes of rejection for cardiovascular defects

It should be noted that the number and percentage of rejections for cardiovascular disease during the second period were materially greater

TABLE 2

Rejections Due to Cardiovascular Abnormalities in 1941 (8627 Men)

Cause of Rejection	No Rejected
Essential hypertension	88
Rheumatic heart disease	39
Mitral disease	14
Aortic disease	2
Mitral and aortic disease	1
Unspecified	22
Neurocirculatory asthenia	36
Organic heart disease type unspecified	10
Tachycardia	8
Congenital heart disease	2
Auricular fibrillation	1
Paroxysmal tachycardia	1
Multiple extrasystoles	1
Total rejections for cardiovascular disease	186
Percentage of total examinations	2.1
Percentage of total rejections	13.8

than those during the first. This difference is due to the increasing belief on the part of the examiners that the standards for acceptance (Class 1 A) must be of the strictest sort. This opinion has been concurred in by recognized cardiovascular experts.

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## SELECTIVE SERVICE PSYCHIATRY

### Schizoid and Related Personalities; Mood Disorders and Psychopathic Personalities

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The dubious theory that psychopathic personalities are related to the major psychoses as 'character disorders' are to the psychoneuroses may justify the combining of the three topics which are touched upon in this discussion. It is in fact a very far cry from the schizoid and related people, who are often highly valuable, if somewhat unstable members of the community, through the cyclothymics who often carry on useful lives in the most conventional manner between their phases of disturbance, to the psychopaths, who by no stretch of the imagination can be conceived to be useful citizens. Historic accident and the Advisory Committee on Psychiatry of the Selective Service System required of the writer that he should undertake to offer some practical suggestions bearing on the diagnosis of registrants who belonged psychiatrically under these three rubrics.

#### Schizoid and Related Personalities

In this presentation the fully developed schizophrenic state will not be discussed. Instead, there will be pointed out, signs of prepsychotic personalities which indicate the possibility that breakdown may develop from either the specific stresses of army life or the changes incident to demobilization and the reestablishment of a civilian career. We have to be concerned not only with illnesses that may develop during the time of military training, but also with the augmented number that may disclose themselves during the subsequent ten years in the reserve corps.

There is less the problem of recognizing the manifest psychotic and more the one of picking out those whose disturbances have not been conspicuous enough to interfere with their getting along in everyday life. Concisely it is the diagnosis of mental health or its absence.

The signs of ill health or personality handicap suggestive of future schizophrenia can be grouped under the general topics of: observable signs of dissociated phenomena during the examination; the nature of what the registrant says about himself; and the manner in which he responds to the examiner. These are the things we can look at and appraise.

The registrant will not show marked evidences of deterioration. bizarre posturing, silly laughter and grimacing, catatonic stupor or excite-



ment, or paranoid delusions. In fact, it is unlikely there will be marked evidence of any clinical entity—only slight signs and clues to be followed up and evaluated.

The accompanying record from the local board may have only the request for a psychiatric examination and no other pertinent data, the first examiner feeling that it is up to the advisory board to eliminate. Having seen a local board in action, I have the impression that the physician members wished to certify as many men as possible, irrespective of psychiatric suitability.

What are these signs and clues? We can mention first the candidate's reactions to physical differences or handicaps. Is he sensitive about the appearance of the scalp or hair? Is premature baldness or alopecia areata a sore spot with him? Is the shape of the head a source of embarrassment? Are the size or shape of the nose, ears, or mouth out of the ordinary? Has he been kidded about them to the extent of causing deep resentment or rebellion at the fate which marked him as different? The face may show acne—current or past, scars or disfigurement. How much does it bother him? Was it severe enough to make him uncomfortable in public? Did he hesitate to ask girls to go out with him? Was he geyed much about it, and if so, what was said? What did he think they were driving at? We might like to know at this point if he associated a bad complexion with masturbation, but unless rapport is good, a direct question may silence him. Perhaps one could ask "What do you think might have caused the pimples?" He may have heard that they come from masturbation or he may ask a question as to its effect on the general health or mind. It is unlikely that the mentally healthy will volunteer much in a short, first interview, and if it is not spontaneously forthcoming, the subject can be dropped. On the other hand, a young man who takes the above mentioned opening as an opportunity to ask advice about sexual matters has probably matured so little in this part of his personality that the rigors of an army camp, with its enforced intimacies, will be a severe strain on his lack of sophistication.

Unusual arm, leg or trunk proportions can be used to get at the candidate's opinion of himself. In short, any physical defect or variant, may be a reason for an unhealthy and crippling attitude and so worth asking about—a lead.

Since prepsychotic personalities often attach unusual significance to physical variation from what they consider the normal, their ideas about themselves are valuable clues as to how healthy and realistic their self-appraisals are.



Now I would like to discuss some details of the interview; what the registrant says about himself, especially how he reacts to questions and to the attitude of the examiner. Although not usually done, it is advisable to have the candidate strip and to make a brief physical examination, since so much more can be seen under these circumstances.

First, are there signs of tension, conspicuous as keen alertness or vigilance or marked by an apparent wooden calm? Before relevant information can be obtained, the registrant must be put at ease, but if this is impossible the persistence of tension is in itself ground for inferring extreme insecurity and questionability for induction. It is pretty certain that if subjects are introduced that he regards as dangerous to his security or prestige, the registrant will become uneasy. If we notice an increase of motor activities or changes in the manner of speaking, we can be rather sure we have approached something significant.

The insecurity may reveal itself in unwitting movements, changes in muscle tension, or sudden contractions, all indicative of disharmony of the personality, conflict, contradictory motives, unconscious determinants, or dissociated processes. It doesn't matter what they are called.

Under tension, mannerisms will appear with noticeable frequency. They may include movements of the eyes, blinking of the lids, changes in the extent of the palpebral fissures, assumption of a dreamy, far-off expression or an intent staring at some object in the room. The pupils may change in size.

The forehead may wrinkle. The head may be cocked at a peculiar angle. Oral musculature may also be involved. Slight changes in facial expression often accompany upper or lower gastro-intestinal movement, peristaltic activity, borborygmus, painful spasm or flatus.

The nostrils may twitch or quiver slightly, inexplicable sniffing may be noticed, or the lips may be moistened nervously. The throat may be cleared unobtrusively. Hesitant or explosive coughing may advertise tensions in the upper respiratory segments. Smiling in an odd way or sighing should provoke interest. Touching the lips, eyelids, scalp, or ears may seem such natural movements as to escape attention unless we are really on the alert. Slips of the tongue are quite common indicators of unconscious meaning.

In attempting to pick out registrants who are largely dominated by oral motivations—those centered about the upper end of the gastro-intestinal tract—the set of the mouth and lips may be a help. The lips in repose may suggest one sort of personality; under tension, a quite different one. The prevailing set of the mouth will reflect conscious attitudes. Changes which seem inappropriate to the content, and those



which may be noted when the guard is dropped, are good clues to dissociated personality trends that are worth further investigation. Slight movements of the lips may be the only indication that the candidate is thinking 'Well, I got by that question all right,' or 'I fooled him on that one.' He didn't find out anything there, and so forth. A set of the lips indicating satisfaction following the recounting of a tale of having put a rival in his place, or of having scored off of a superior may suggest an obstinately resistant person. If this is confirmed by a history of continual conflict with authority figures, the possibilities for trouble making and insubordination in a setting demanding prompt obedience, need to be considered. A man with a life long pattern of argumentation and disagreement will probably not be treated by the sergeant with kindly solicitude. While one may personally feel that army life would do the fellow some good the good of the army is the major factor to be considered.

Smelling the fingers, movements of the hands toward the nose or genitals such a casual performance as reaching for a cigarette, increased rate of smoking or suddenly putting out a cigarette that has just been lighted may be signs of inner disquietude.

One may observe quick, slight jerks of the hand, arm or leg, or fibrillary twitching of muscles unaccompanied by gross movement. The posture may be changed frequently, the knees or ankles being crossed and recrossed or the restlessness may approach frank fidgeting.

No single one of these signs of a lack of unitary motivation may be diagnostic or pathological in itself, but if their meaning is followed up one finds that it becomes possible to make a shrewd guess as to the kind of soldier the man would make.

Schizoid traits are noted among the strikingly athletic as well as among those with the more frequently mentioned asthenic habitus. In the case of one registrant a bank teller, questions about two items on the record, namely, a disproportion between height and weight and an apparent lack of vigor, disclosed a history of frequent illnesses—several days in bed at a time—recurrent fainting, marked susceptibility to fatigue and a suspiciously obsessional preoccupation with diet and with efforts to gain weight.

Some natural questions about build and appearance may lead without effort to a more personal discussion of family resemblances and dissimilarities, personal ambitions and disappointments, attitudes toward work, fellow employees male and female friends, diversions and recreations. In this instance, poverty had resulted in prematurely youthful work on a farm with no resultant building up of physique. Unaccounted



for illnesses led to a preoccupation with health and an avoidance of anything regarded by him as detrimental to health. He neither smoked nor drank. He joined a religious sect, which held extreme views on diet. Although he did not consider himself lonely, he had few friends—no intimates. Marriage, he stated, was out of the question because of finances. This seemed only a part truth as he had never shown an interest in a girl. He was 27. Recreation and diversion were almost nonexistent for him. His serious mien suggested worries. He denied worrying about himself, but, on pressing, admitted concern about his family.

His continued efforts to gain weight without success suggested the possibility of a high normal metabolic rate and recommended examination of the pulse for possible disordered action of the heart. The hands revealed no tremor, but moisture of the palms was observed. On inquiry, the registrant recalled that sweating of the axillæ and generally perspiring feet were common experiences irrespective of the environmental temperature.

While the pulse was being taken during exercise, the door of the examining room opened and another registrant entered. The pulse quickened and became irregular for several seconds with extra systoles, and eight to ten minutes later was still 96. It had been reported on the first examination by the local board as having returned to 76 within two minutes following similar exercise.

This man's mental health is not too secure if he has to preserve it by deflecting unconscious attitudes into gastrointestinal and circulatory symptoms. You can picture this man in the army with its rigid routine, severe physical demands, and lack of solicitude for the somatic peculiarities of the individual. And yet as a respected bank clerk he will probably carry on very well.

Marked anxiety and obviously apprehensive timidity are not seen very often, but when they are, one can remark at once that the registrant appears uncomfortable or frightened, and inquire whether it is a frequent occurrence. What situations provoke the disturbance? Does it occur only in unfamiliar surroundings or has he suffered embarrassment among people, supposedly his friends? What does he anticipate will happen to him? Does he believe he will be inducted? Here, we might get some previously unmentioned, queer belief about himself or a hypochondriacal concern about some organ, the bizarreness of which would be pathognomonic. What does he anticipate when he gets in the army? Does he expect to advance or remain a private? Does he expect any trouble?

If the answers reveal a doubt or fear of getting along with the officers,



or other men in the company indicative of concern about living in intimate contact if there is fear of ridicule anticipation of taunts about courage or manhood or sexual powers we will probably not be wrong in surmising the possibility of panic and the development of a catatonic state We can imagine that the barrack mates will not have much patience with anyone who has bolstered his feelings of inadequacy by books on the psychological mastery of others—*The Secrets of Success How to Win Friends and Influence People*—nor will they be tolerant of the special props the queer performances that have been making life bearable for the pre schizophrenic person Ashamed to have them known exposed to ridicule if observed by others the pressure can get pretty heavy It is not hard to guess the outcome

Those who maintain the aloof detachment of unconcern or what appears to be a gentlemanly reserve are generally hard to get at Their techniques of maintaining social distance are highly developed Something in their manner during the physical examination may have caused the local examining physician to suspect queerness or difference and to have resulted in referral Usually there will be no starting point of inquiry referable to a specific symptom and a direct question as to why the registrant was referred to the psychiatrist may be met with the equally direct answer I don't know Maybe he has made up his mind that induction is inevitable and that it is useless to talk about it Denial of any concern about the draft may sound convincing Leading questions as to suspected symptoms are shrugged off One has a sense of stalemate

Sometimes a frank statement of fact may elicit the desired information You have been referred to me because the doctor who gave you the physical examination did not quite know what to make of you What did you think of that examination? Well it was all right—

But what? Well I didn't see the reason for all of it What did he examine that you did not think necessary? Oh I just didn't like his manner Go on Oh I don't know I don't like people feeling my privates or anus He will probably not say anus Tell me about it Well that's just none of his business I didn't like the way he looked at me A direct question—How did he look at you—will probably receive the answer I don't know or I just didn't like it An indirect question—What did you think of him—may elicit Oh nothing Surely you thought something? Well to tell you the truth he looked at me kind of funny You know At this point I believe the inquiry may well be dropped There is enough revealed for us to be sure of future homosexual difficulties

Or suppose that the direct statement—Something about you caused



the doctor on the local board to refer you to me"—arouses only antagonism. Then a remark to the effect that some difficulty must have been suspected and that the first examiner may have thought it would keep the candidate out of the service or cause trouble after he got in, may reduce the antagonism and permit exploration. A sincere and professional interest in his suitability for service life, should pave the way.

Persons whose attitudes reflect strong compulsive drives, or a destructive sadistic bent, cannot adjust well in the service. Intimate contacts will make them too uncomfortable. In turn they will be a sarcastic scourge to others with less well organized defenses. Their influence on morale is correspondingly disintegrative. They are rebellious and do not accommodate easily to any disciplinary regime.

Candidates who show perplexity or confusion, failure to get the meaning of questions, apparent failure to hear because of preoccupation, do not offer much of a diagnostic problem. More difficult to gauge are the modestly unobtrusive, quiet and gentle mannered chaps and certain others of rather youthful appearance with sensitive features and an air of refinement, sometimes with slightly effeminate mannerisms or gestures. How will life in the training camp affect them? How will they like the idea of a common shower, of having no privacy? Do they not dread enforced association with those of a different cultural background? How will the appetite react when coarse allusions are made to the food in the mess hall? Are they disgusted by dirty stories whose point is strongly oral or anal? Do they experience discomfort when sexual matters are vulgarly referred to? Do they seem to feel that all women are sacred? Have they failed to break away from the early attachment to the mother and to find a substitute? Fear of impotence might be serious and its actuality a profoundly disturbing problem. One may feel that these babies need to be toughened, but service life makes more immediate demands on everyone concerned, than it offers opportunities for hurrying these preadolescents on to a well developed maturity.

The integration of their personality has not included adult sexuality and in all probability they are in the reservoir from which the catatonics will be drawn. Conversely, the chesty braggart who ostentatiously looks forward to a release from home restrictions and to the more independent freedom which he imagines will be true of the army, may be equally insecure but hiding it in a different way. He may be the ready recipient of venereal disease and so marked for the hospital rather than fit for duty. As the psychosexual attitude is developed in the interview, mannerisms and accessory movements may become much more conspicuous.



This can be safely regarded as either a contradiction of what the candidate is asserting or as evidence of insecurity because of a conviction that the examiner is disapproving or condemnatory.

Now let me touch briefly on the paranoid personalities with which we are all so painfully familiar. Before classical ideas of reference and delusions of persecution develop these people present plausible excuses and reasons for unsuccessful adjustment. One might be misled were it not for the inference that it was always the fault of someone else.

Bridling at questions, becoming angry at the necessities of the examination, showing scorn for the stupidities of other registrants and resentment at having been drafted at all are expressions of their conviction of extravagant self importance. Suspicion of the purpose of the examination may be strong. Why do you ask? What do you want to know that for? What's that got to do with it? all reveal doubt as to the examiner's intent or *bona fides*.

These are the people who are adept at evasion and noticeably careful to make their answers non revealing.

An attempt has been made to picture some of the types of personality that one will meet and to indicate some of the signs by which the unstable, the immature and the prepsychotic can be identified.

To state the matter as simply as possible the absence of mental health in this group of prepsychotic and schizoid personalities is objectively indicated by the presence of dissociated processes at work in the various systems of the body. These may involve the psychic functions only or they may be evidenced in the voluntary or involuntary muscles, the cardiac vascular system, the gastrointestinal tract, in the secretory glands, both internal and external and in the genitalia. Wherever found they are to be potentially regarded as forerunners of disaster.

Whatever adaptabilities these people have, whatever usefulness they can manifest, can scarcely be expected to show to its best advantage under the disciplinary regime of the service with its unconcern for the person, its heartless ridicule of the peculiar and its intolerance of the misfit. The Army just has no room for them.

Of the many who will survive civilian life, perhaps be very useful citizens, there are few indeed who if inducted into the service will escape the tragedy of illness with its devastating effects both on the personality and on the taxpayer.

### Mood Disorders and Psychopathic Personalities

These topics call for attention to two groups of people not outstandingly different from the general run except when they are having acute



episodes in their career lines. Unlike the psychoneurotic and schizophrenic who show definite signs of instability during the examination, the diagnosis of the manic-depressive and psychopathic personality has to be based on a knowledge of a longitudinal section of their lives, rather than on the few slight but suggestive clues which may be seen in the interview.

### **The Manic-Depressive Personality**

It is reasonable to expect that a person who has suffered or is likely to suffer a manic-depressive psychosis may show some characteristics of the disorder in the prepsychotic personality, or in the free interval between attacks.

Taking the chief characteristics of the manic phase to be flight of ideas, push of speech and distractibility—what diminished form or traces of these may we observe?

An attenuated form of a flight of ideas may be seen in the frequent change of subject—the direction the conversation takes. Subject matter will not be unusual, but there will not be a calm and considered progression of thought. There will appear to be a variety of interests superficially and sketchily treated.

Push of speech will not be pathological in rapidity but may show in a jerky mode of expression or a rattling along without regard for the time of the examiner. Quite a bit of conversation will be volunteered in a slightly forced talkative manner, but what is said will be rather superficial.

A mild degree of distractibility will be found in the number of questions the candidate asks, the numerous things that catch his attention, but do not hold his interest, and questions partially or entirely irrelevant to the business in hand.

He perhaps will be a little impatient and tend to interrupt the examination. Impatience and the tendency to interrupt may be the first signs, or perhaps the only evidence of the irritability we know underlies the pseudo-jiviality which is maintained on the surface. He may be quick to contradict but should he feel the need of restraint may show his displeasure only by a change of posture or facial expression. He will readily admit to quick anger, but will insist it passes at once—that he holds no grudges. There is no appreciation on his part of the essential destructiveness which underlies the popular conception of his humorous good fellowship and friendliness. He enjoys the practical joke and the witticism at the expense of others.

Being insecure in his interpersonal relations he surrounds himself with friends, most of whom, on close inquiry, turn out to be acquaintances, useful to him in one way or another.



Although there is an inner need to create a good impression in the examining line of the induction board, his somewhat ebullient camaraderie will only serve to interfere with orderly and methodical examination. His sallies of wit are calculated to discomfit others rather than to facilitate ease.

Such are some of the traits of the manic personality which may be seen at the time of examination. To evaluate the meaning of these slight indications, and to estimate the probability of future psychosis and probable fitness of the man for service life, it is necessary to take a searching history and to make a fine diagnostic discrimination.

The amount of irritability shown at the time of examination or revealed by the history may be one criterion of how successful he has been in achieving stability.

Persons with a depressive temperament present the reverse of the above picture. We will see a reduction of psychomotor activity, a solemn or morose mien, an air of *What's the use*, or in more noticeable form an appearance of positive dejection. Such a man will say little, volunteer nothing and answer in monosyllables.

The flight of ideas of the manic seen in the variety of interests and change of direction of the hypomanic personality is reduced in the depressive to a real poverty of associations.

The push of speech is reduced in mild forms to a seemingly polite reticence, but as one attempts to draw out such a chap there will be noticed a dearth of information and in some instances a stubborn withholding will be detected. Distractibility is restricted to an ever narrowing circle of outside—that is, interpersonal interests.

This variable rate of change of the subject and direction of thought may perhaps be used as a rough guide in estimating suitability for induction. For example in exaggerated form in the hypomanic, the excessive rate of change of associations will mean a soldier too full of ideas to be well disciplined. He will be too quick on the trigger.

If not exaggerated, if within average limits it will mean a man capable of quickly orienting himself to new facts and adapting himself to new conditions. If the rate of thinking speed is moderately reduced we may predict a dull unimaginative drudge who thinks too slowly and gets there just too late.

If the ability to have new associations, that is, if the change of direction is too inhibited, we will see a man who in a crisis cannot function at all, who just cannot think.

In the pathological ranges of these varying degrees of changes in speech, of thinking and talking the attentive ear will catch a common



factor. The data will be superficial and impersonal, revealing a noticeable lack of personal disclosure. One will not get the impression of a warm and genuine friendliness.

The younger men of the draft age of depressive temperament will not have made many friends. If they are asked, "Do people soon get to like you?", the answer will be "No." Why not? After a silence—"I don't know." Was it always that way? "I guess so. I don't know." To what do you attribute it? There will be more silence, a little restlessness, perhaps seen in the changing of posture or a deepening of gloom. No real data of personal significance will be forthcoming.

The irritability of the manic may be seen in the form of surliness and obstinacy which lurks behind the superficial submissiveness and docility of the mild depression. One may call to mind the intractability of the involuntal or agitated depression for a more vivid picture of this.

The dejection of the advanced depression which conceals a growing bitterness may be only hinted at in the *What's the use* attitude of the younger man. There will be a decided air of justifiable pessimism in his expectations of army life. It will not be tolerant of moodiness.

Those who have already experienced cyclothymic swings will have noted days or periods of efficiency when they worked with zest and were ebullient in their contacts. They will contrast this with other times when they were slowed up, unable to get things done and shrank from seeing people. Diurnal variation is reported by some, the depressed finding it hard to get started in the morning, the manic starting off with exuberance but becoming increasingly irritable as the day wears on. One put it this way: "When I'm up—the world is my oyster. When I'm down, I'm sunk." Perhaps the simplest of questions, "You seem to be down now, are you ever up?", or *vice versa*, will reveal the cycle. Those prone to the "blues" will not be happy in the army, nor will the army appreciate the gloom they shed.

To sum up the depressive personality, it can be said to show a poverty of associations, a noticeable superficiality, a lack of warm, friendly interpersonal relations and a quiet, passive, hindering quality unsuited to smooth functioning in the service.

### **Psychopathic Personalities**

We are on even more difficult ground in trying to pick out the psychopathic personalities in a single interview or in the induction line. It is probable that only the glaringly obvious fellow will draw attention to himself by his talk and that the majority will present no outstanding differences from the general run. In these cases we are very dependent



on a life history for diagnosis

The commonly accepted conception of a psychopath is a person who cannot learn by experience, who fails to recognize the limiting or restraining influence of reality. Such a person recognizes no law but his own immediate need.

The history of the psychopath is replete with a succession of misadventures. They are truly the socially misfit. It is likely that the school record though academically acceptable will be marked by difficulties with the teachers, truancy and various forms of delinquency. They not only get into trouble themselves but they get others into trouble.

They will lie and steal as suits their purpose. Some will have acquired a police record or will have been referred to a Social Service Agency, a psychiatric clinic or the psychopathic ward of the City Hospital. Alcoholism begins early in their lives and continues. They are reckless drivers with a high proportion of accidents.

Many of them will have been sexually promiscuous, either hetero or homosexually, but characteristically there will have been no permanency in any of these relationships. Inability to look ahead causes them to omit prophylactic precautions thus needlessly increasing the V D rate.

Perhaps the most outstanding fact of the history is their irregular work record. There will have been frequent changes of jobs without adequate explanation of the reasons for such changes. Answers to the question—'Why did you leave this job?'—will often be 'I don't know,' or 'I just got tired and quit.' Their unconcern is striking.

These are some of the facts which the local examining physician may already know about the candidate and which the advisory board psychiatrist can elicit either from the registrant or obtain through a Red Cross or Social Service history.

When we come to the interview itself, a few characteristics of the psychopathic personalities will be noted. There is first the marked fluency of tongue which characterizes their immediate reaction to a new situation. They have the 'gift of gab' and a smoothness of attitude and speech which among the more highly intelligent may suggest a high order of competency. They will assume an air of easy familiarity with the examiner during the interview and if they feel the examiner is friendly they may enlarge upon their history in a boastful manner, brag about the escapades and jams they have been in and relate with pride how they have gotten out of them.

Even though hard pressed by the examiner on points showing discrepancies in accounts of themselves they will show little anxiety or



discomfiture in their manner of speaking. Sweating, pulse changes or quickened respirations may be the only clues that they are under tension. Almost certainly there will be no voice changes or marked disruption of their poise. Many of the deliberate malingerers will be drawn from this group.

Like the manic their essential relationships with others are disruptive and destructive. Being unable to look ahead intelligently, they may view the army experience as a lark, expect rapid promotion and special favors, and look forward to the idea of wearing a uniform. Being totally undisciplined they will run afoul of army regulations with attendant disruption of routine. They have great nuisance value in themselves, but carry no great weight of influence among the stable members of the outfit. With other psychopaths, however, they carry weight, and two or three in a company can be a very disturbing influence.

They live in and for the moment, have a keen intuitive empathy which enables them to shift positions rapidly, but they have no real alertness to or comprehension of the implications or complications resulting from their behavior.

### Conclusion

These two groups of people are among the hardest to diagnose, or to predict. They may show clinical evidence of instability during examination, but the examiner is for the most part dependent on a life long history supplied by others.

Local Board Members in small towns and rural areas are apt to know personally the candidates and their family background. In larger metropolitan areas the future plan is to use social agency data.

In Maryland the names of all registrants are cleared through the office of the Commission of Mental Hygiene and those persons found to have had residence in either public or private institutions in the state are so reported to the local boards. Such hospitalization should automatically disqualify a man for induction.

From the standpoint of the Army which has to cope with them now and the Veterans Bureau which has to care for them later, persons suspected of manic-depressive or psychopathic personalities are far better off if they are left to the pursuit of their civilian activities than if they are inducted into a service which makes more demands upon them than they are able to endure.



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# DIAGNOSIS AND TREATMENT OF SECONDARY SHOCK

## *A Study of 24 Cases*

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Since this investigation began we have treated over 100 cases of primary or secondary shock. The present report, which concerns 24 cases of secondary shock that were selected for systematic study, provides data sufficient to justify tentative conclusions that can be tested by other observers with more material at their disposal. The findings support the opinion and recommendations expressed in the current M.R.C. memorandum (1940).

### Case Records

CASE 1.—Male, aged 50. Seen 2½ hours after injury. Right leg completely destroyed from 2 in. below knee and small hole in abdominal wall, though splinter had not entered peritoneal cavity. Tourniquet had been applied 15 min. after injury and morphia gr. ¼ given 15 min. later. Mentally dull but rational, no pain, no thirst, pallor ++, cyanosis of lips and fingers ++, no sweating, very cold. Hb finger 100%, vein 104%, haematocrit 40%. Pulse impalpable, B.P. not recordable.

After 1 pint plasma in 15 min. P. 108, B.P. 40/1. After 2nd pint plasma in 15 min. P. 110, B.P. 60/40, Hb finger 70%, vein 60%, haematocrit 25.5%. After 3rd pint plasma in 12 min. P. 160, B.P. 80/50. After 4th pint plasma in 23 min. P. 120, B.P. 105/55, Hb finger 47%, vein 45%, haematocrit 19%. Had by now greatly improved in colour; pain in legs and abdomen. Had to wait for admission to theatre on account of congestion, during which time B.P. fell to 80/50 and 1 pint blood administered. Left theatre with B.P. 100/70. Amputation of leg through upper third of thigh, abdominal wall opened and f.b. removed. Anaesthetic G.O.E. After 24 hours condition excellent; P. 78, B.P. 115/70, Hb finger 52%.

CASE 2.—Male, aged 26. Seen 3 hours after injury. Wound in left loin 8 in. in diameter; multiple superficial wounds, abdominal wound, small wounded right shoulder. Morphia gr. ¼ 40 min. after injury. Warmed with electric blanket for 45 min. before transfusion. Mentally clear and rational, pain slight, thirst ++, pallor ++, cyanosis slight, no sweating, hands very cold. P. 86, B.P. 50/30.

After 1 pint blood in 20 min. P. 92, B.P. 70/60. After 2nd pint blood in 20 min. P. 94, B.P. 80/75. After 3rd pint blood in 20 min. P. 100, B.P. 95/75, colour greatly improved, operation started: débridement, intestinal resection. At



end of operation P 90 BP 90/70 After 24 hours P 100 BP 110/80, general condition good

CASE 3—Male aged 21 Seen 3½ hours after injury Multiple small injuries of back legs and arms gaping hole in right buttock 9 in in diameter, buttock almost completely removed perforating wound left wrist joint. Morphia gr ¼ 1¼ hours after injury Warmed with electric blanket for 1¼ hours before transfusion Mentally clear pain ++ thirst + pallor ++, cyanosis ++ sweating slight T 95° F P 82 BP 40/30 Hb cr 120%, vein 100%, haematocrit 43%

After 1 pint plasma in 20 min P 100 BP 70/40 After 2nd pint plasma in 20 min P 120 BP 80/45 After 3rd pint plasma in 20 min P 128 BP 100 55 Hb cr 80% Greatly improved but pallor still extreme 1 pint blood given in 30 min P 120 BP 100/60 Started bleeding from buttock 1 pint blood given in 30 min During operation of débridement at which much bleeding 2 further pints blood administered each in 15 min Anaesthetic GOF After operation P 110 BP 112/70 After 24 hours general condition good P 120, BP 115/80 Hb 78%

CASE 4—Male aged 20 Seen 4 hours after injury Multiple wounds and compound fracture of both legs Mentally clear not in great pain thirst ++, pallor ++ cyanosis of nails no sweating complained of cold Pulse impalpable BP 60/30 Morphia administered

After 2 pints blood each taking 10 min P 120 BP 115/65 Great improvement in general condition cyanosis disappeared treated by warming and 1 pint blood by drip until turn came for theatre During operation received 1 more pint blood and left theatre with P 118 BP 90/50

CASE 5—Male Seen 2 hours after injury Severe scalp wounds one ear off extensive laceration left arm and probably intrathoracic injury Mentally clear colour ashen grey complained of painful breathing P 155 BP 70 Warmed and morphia gr ¼ administered

After 4 bottles plasma in an hour P 120 BP 120/70

CASE 6—Male aged 23 Seen 4½ hours after injury Simple fracture left femur compound fracture right femur fracture left clavicle left Colles's fracture abrasions head Morphia gr ½ given Mentally clear pain ++, thirst ++ colour normal sweating nil not cold BP 75/60 P 120

After 1 pint plasma in 8 min P 104 BP 105/80 After 2nd pint plasma in 10 min P 92 BP 120/90 Anaesthetic begun Had 3rd pint plasma by drip occupying 45 min At end of operation P 132 BP 145/50 Patient collapsed and died shortly afterwards Was found to have multiple injuries including fractured base blood in csf fracture ribs small tears in liver and spleen haemorrhage into right suprarenal

CASE 7—Male aged 30 Seen 2½ hours after injury Very large wound in back involving right kidney Had received morphia gr ¼ 2 hours after injury Apathetic pain ++ thirst ++ pallor ++, sweating slight cyanosis slight cold shivering Pulse uncountable BP 95/60 Hb vein 120% haematocrit 43%

After 1 pint plasma in 5 min P 150 BP 100/65 After 2nd pint plasma in 10 min P 120 BP 105/70 Hb vein 94% haematocrit 33% After 3rd pint plasma in 30 min P 140 BP 110/80 Hb vein 74% haematocrit 26% Sent for operation of débridement and ligature during which received 1 pint blood 2 more pints blood given next day After 48 hours condition fairly good P 120 BP 110/80 but passing much blood in urine Died 3 days later

CASE 8—Male aged 29 Seen 2 hours after injury Shrapnel wounds both



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legs, compound comminuted fractures right and left tibia and fibula, machine-gun bullet wound in left loin, not penetrating abdomen. Tourniquets applied to both thighs; given morphia gr.  $\frac{1}{4}$  an hour after injury and again an hour later. Put to bed with foot raised and warmed. Mentally clear, pain +, thirst +, pallor +, cyanosis of nails, sweating ++, cold, pulse impalpable, B.P. 60/40.

One hour later, after 1 pint plasma in 10 min. pulse flickering, B.P. 70/?. After 2nd pint plasma in 15 min. P. 120, B.P. 90/55. After 3rd pint plasma in 50 min. P. 110, B.P. 115/75. Taken to operating-theatre and on table for 2 hours, during which fourth pint of plasma administered by drip. Condition rapidly deteriorated when injured limbs were manipulated. Died few hours afterwards.

CASE 9.—Male, aged 16. Seen  $1\frac{1}{2}$  hours after injury. Compound fracture right thigh, much laceration and pulping of bone, and compound fracture lowest third left leg, much laceration and pulping of bone; gross swelling of both limbs above site of injury. Morphia gr.  $\frac{1}{2}$  45 min. after injury. Mentally clear, pain ++ when moved, thirst ++, pallor ++, cyanosis of lips +, sweating slight, cold. P. 112, B.P. 80/55, Hb finger 90%, ear 95%.

After 1 pint plasma in 12 min. P. 108, B.P. 95/70. After 2nd pint plasma in 20 min. P. 108, B.P. 95/70. After 3rd pint plasma in 45 min. P. 108, B.P. 110/75. Taken to operating-theatre for double amputation, during which 1 pint blood given in 28 min. and 1 pint plasma as drip. Left theatre with P. 104, B.P. 120/70. Uninterrupted recovery.

CASE 10.—Male, aged 26. Seen  $2\frac{1}{4}$  hours after being hit on back by lump of rock; very large bruise left kidney region, with great swelling left flank, and ? left pneumothorax. Given morphia gr.  $\frac{1}{2}$  an hour after injury. Mentally clear, pain in chest +, thirst +, no pallor, cyanosis +, sweating slight, temperature normal, P. 130, B.P. 70/55, Hb vein 97%, haematocrit 37%.

After 1 pint plasma in 15 min. P. 108, B.P. 100/50, Hb vein 84%, haematocrit 33.5%. After 1 pint blood in 3 hours B.P. 125.

After 24 hours condition satisfactory.

CASE 11.—Male, aged 28. Seen  $2\frac{1}{2}$  hours after injury; compound fracture right femur, tibia and fibula, and fracture dislocation right carpus and metacarpus. No tourniquet. Morphia gr.  $\frac{1}{4}$  given. Mentally clear, no pain, thirst +, pallor +, no cyanosis, sweating +, temperature normal, P. ?, B.P. 70/50.

After 1 pint of blood B.P. 90/50. While 4 pints plasma were given in 1 hour 20 min. there was progressive improvement, resulting in B.P. 115 though bleeding continued. Excision of wounds and reduction of fractures begun. Left theatre with B.P. 110.

CASE 12.—Female, aged 50. Seen 3 hours after injury; deep wound right leg, smashed right and left feet (hanging by threads) with tourniquets still applied. Morphia gr.  $\frac{1}{4}$  had been given 30 min. after injury and repeated  $2\frac{1}{2}$  hours later. Mentally clear, no pain, thirst +, pallor +, cyanosis +, no sweating, temperature normal, B.P. 95/65, P. 58, Hb finger 95%.

After 1 pint plasma in 20 min. P. 80, B.P. 110/80. After 2nd pint plasma in 40 min. P. 76, B.P. 118/85, Hb finger 74%. During this 40 min. consumed 2 cups sweet tea; colour greatly improved. Taken to operating-theatre for amputation and débridement.

After 24 hours condition good; P. 80, B.P. 115/80. Six weeks later B.P. when lying in bed 160/120.

CASE 13.—Male, aged 30. Seen 2 hours after injury; simple comminuted fractures of left femur, left tibia and fibula, and at lower ends of right tibia and fibula. Morphia gr.  $\frac{1}{2}$  given an hour after injury and warmed up, but



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round right shoulder. Morphia gr.  $\frac{1}{4}$  given  $1\frac{1}{2}$  hours after injury and warmed with blankets. Drowsy, pain slight, thirst  $++$ , pallor  $+$ , cyanosis  $+$ , no sweating, cold, pulse impalpable, B.P. 50/35, Hb ear 92%, vein 89%.

After 1 pint plasma in 10 min. P. 108, B.P. 80/45. After 2nd pint plasma in 40 min. P. 110, B.P. 95/60. After 3rd pint plasma in 30 min. P. 130, B.P. 115/70, Hb vein 55%. Taken to operating-theatre with 1 pint blood by drip; extensive débridement lasting  $1\frac{1}{2}$  hours accompanied by much bleeding. Died 6 hours after admission.

CASE 19.—Female, aged 19. Seen 3 hours after injury; severe crush of both legs almost severing legs below knees, 3 puncture wounds of abdomen subsequently found to have penetrated caecum, 1 puncture wound left thorax. Morphia gr.  $\frac{1}{4}$  given and tourniquets applied to both thighs 30 min. after injury. Morphia gr.  $\frac{1}{8}$  given 2 hours after injury. Mentally clear, pain severe, thirst  $++$ , pallor  $+$ , cyanosis  $+$ , sweating  $+$ , very cold, pulse impalpable, B.P. unrecordable.

After 1 pint plasma in 10 min. P. impalpable, B.P. 40/unrecordable. After 3 more pints plasma in 60 min. P. 144. After 1 pint blood in 45 min. P. 140, B.P. 98/unrecordable. Delay in transfer to theatre and in operation; condition deteriorated although drip of blood running; blood administered in theatre but died 8 hours later.

CASE 20.—Female, aged 38. Seen 8 hours after injury; multiple abrasions and large lacerated wound of face tearing both lips and whole of right side of cheek. Morphia gr.  $\frac{1}{4}$  given 6 hours after injury. Mentally clear, pain  $++$ , thirst  $++$ , pallor  $+$ , cyanosis slight, no sweating, extremities cold, pulse uncountable, B.P. 90/60. No improvement with conservative measures.

After 1 pint plasma in 20 min. P. 124, B.P. 120/60. Another pint blood administered during operation for cleaning face, débridement and suture of left side of mouth. General condition 2 days later excellent.

CASE 21.—Male, aged 28. Seen  $1\frac{1}{2}$  hours after injury; blast effects to lungs, ruptured small intestine, extraperitoneal rupture of bladder, fractured pelvis, torn mesenteric vessels. Morphia gr.  $\frac{1}{4}$  given 1 hour after injury. Just conscious, pain  $++$ , thirst  $++$ , pallor  $++$ , cyanosis  $++$ , sweating moderate, stone cold, pulse impalpable, B.P. 50/?.

After 1 pint blood in 7 min. P. 140, B.P. 60/?. After 2nd pint blood in 15 min. P. 110, B.P. 80/?. After 2 pints plasma in 52 min. P. 88, B.P. 110/70. During operation 2 pints blood administered slowly. Survived 24 hours.

CASE 22.—Female, aged 20. Seen  $1\frac{1}{2}$  hours after injury; compound fracture left femur, extreme laceration left leg, wound right knee and left elbow, multiple small wounds and fractured pelvis due to splinter discovered at operation. Morphia gr.  $\frac{1}{4}$  given  $\frac{1}{2}$  hour after injury. Mentally clear, pain  $+$ , thirst  $++$ , pallor  $+$ , cyanosis slight, sweating  $++$ , very cold, P. 70, B.P. 55/?.

After 1 pint plasma in 25 min. B.P. 80/?. After 2nd pint plasma in 50 min. P. 110, B.P. 50/?. After 3rd pint plasma in 20 min. P. 110, B.P. 70/40. After 4th pint plasma in 35 min. B.P. 85/40. After 1 pint blood in 60 min. P. 133, B.P. 100/60. Taken to operating-theatre where  $2\frac{1}{2}$  pints blood given. Died during operation.

CASE 23.—Male, aged 52. Seen 3 hours after injury; fractured right femur, scalp wounds, severe bruising of back. Morphia gr.  $\frac{1}{4}$  given  $\frac{1}{2}$  hour after injury. Mentally slow, pain, thirst and pallor slight, cyanosis  $+$ , sweating  $+$ , very cold. P. 86, B.P. 60/40.

After 2 pints plasma in 20 min. P. 88, B.P. 145/80. Operation, pin through tibia; 72 hours later B.P. 160/76.

CASE 24.—Male, aged 25. Seen 3 hours after injury; compound fracture



right tibia and fibula puncture wounds both lower limbs, 3 puncture wounds shoulder puncture wound right chest Morphia gr  $\frac{1}{4}$  given  $\frac{1}{2}$  hour after injury Mentally clear, pain +, thirst ++, cyanosis slight, no sweating, cold, P 144, B P 70/50

After 1 pint plasma in 10 min P 140 B P 85/65 After 2nd pint plasma in 20 min B P 100/70 After 1 pint blood in 30 min P 100, B P 105/80 A further pint blood administered as slow drip during operation Died 5 hours later probably from bilateral haemothorax

### Primary and Secondary Shock

Primary shock due to psychogenic and neurogenic influences is common among air raid casualties which reach hospital soon after their injury Most are at least frightened and shaken These, from primary shock alone may exhibit pallor, sweating feeble pulse and low blood pressure or even be unconscious Differentiation of primary from secondary shock is easy with extremes of injury, when the wounding is of such severity that immediate transfusion is obviously required and delay would be dangerous or when there are no wounds and transfusion would be both unnecessary and foolish But in intermediate cases differentiation is only possible by allowing a period of observation, the degree to which rest in the recumbent head low position combined with warmth and morphia produces improvement will depend on how far the symptoms are due to primary shock If at the end of an hour the blood pressure is still below 100 mm Hg some degree of secondary shock is probable and transfusion should be done before an anæsthetic is given But if within the hour the blood pressure rises and stays above 100 mm Hg it may be assumed even though a normal figure has not been completely reached that the shock was mainly primary and that transfusion is not necessary for resuscitation though it may well be required during operation The blood pressure should be taken every 15 min so that patients who are losing way may be transfused without delay In order to carry out this work satisfactorily a special resuscitation ward must be established between the reception point and the operating theatre All the 24 cases here described had either wounds so severe as to brook no delay in instituting transfusion or a blood pressure which failed to recover to 100 mm Hg with rest, warmth and morphia

### Assessment of Severity

In general we have found that the blood pressure is the most reliable measurable factor for assessing the severity of secondary shock and that other clinical manifestations are variable and not quantitative

The pulse rate has not always been as rapid as it is generally assumed



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to be in severe secondary shock nor does it regularly rise in proportion as the blood-pressure falls. Thus 5 cases (2, 3, 15, 16, 22) had rates of 86, 82, 104, 92, 70 with systolic blood-pressures of 55 mm. Hg or less, and one (12), who proved in a follow-up to be a hypertensive, had a pulse-rate of 58 with a systolic pressure of 95 mm. In the remainder the pulse-rate ranged from 110 to 155 and did not appear to bear any constant relation to the blood-pressure. The response of the pulse-rate to transfusion was even more irregular, in strong contrast to the response of the blood-pressure.

The *mental state* in 17 cases was clear and rational. This point which is of great practical importance—that the mental state is no index of the severity of shock—was repeatedly stressed by observers in the war 1914-18, who found that in the absence of head injury a clear normal mind was usual in secondary shock even within a few minutes of death.

As to *pain*, all of our 24 patients had had morphia; pain is recorded as absent in 4, slight or moderate in 8 and severe in 11, and was not recorded in 1.

*Colour-changes* are common but in no way quantitative; 22 out of 24 patients showed obvious pallor and most had also cyanosis of the lips and nails. Extreme pallor in association with a relatively high blood-pressure suggests intense compensatory vasoconstriction.

The *general temperature* of all severe cases is invariably subnormal and the extremities feel cold. This feature, however, depends greatly on the atmospheric conditions, the exposure during transit and the efficiency of the methods for warming. *Sweating* was present in 15 cases but the amount was by no means related to the degree of shock.

The records of *blood-pressure* are shown in table 1. With two exceptions (7, 12) the most severely wounded had the lowest blood-pressures. The two exceptions are instructive. Case 12 was found in a follow-up to be a hypertensive having a blood-pressure of 160/120 when lying in bed; her initial blood-pressure of 95 mm. was therefore a relatively large fall from normal. Case 7, though severely wounded and exsanguinated, nevertheless appeared to be capable of maintaining his blood-pressure at 95 mm. Hg by intense vasoconstriction. Our experience of over 100 cases shows that this feature is a real entity especially in young subjects seen soon after wounding. The phenomenon is suggested by an intense pallor in association with an unexpectedly high blood-pressure. In the particular case here recorded this view is supported by the response to transfusion, in that 3 pints caused a rise of only 15 mm. in blood-pressure though it much improved the man's general condition. Apart from these two cases there has been a remarkable correlation



between the reduction in blood volume and the fall in blood pressure while restoration of blood volume by transfusion has been found to be associated with a proportional recovery in blood pressure (tables I and II)

### **Treatment and Assessment of Recovery**

It is generally accepted that the symptoms of secondary shock are caused largely by gross reduction in blood volume which leads to an inefficient circulation, later to irreversible tissue cell changes owing to malnutrition and finally to circulatory failure. The obvious treatment is to restore blood volume. Information is required as to the best fluid for this purpose, when to transfuse, in what amount and at what rate. From the physiological aspect whole blood is needed by those whose reduction in blood volume is due mainly to whole blood loss and this is usually the case with those who are neither burned nor crushed and who are seen soon after wounding before complex hæmatological changes have occurred. We have analysed our cases in relation to fluid, time, amount and rate but have used more plasma than blood with a view to obtaining information as to its efficiency as a volume restoring fluid.

It has already been indicated that transfusion without delay should be carried out on those with serious wounds and a dangerously low blood pressure, on those whose blood pressure does not recover to 100 mm Hg within an hour of routine resuscitation and on those whose blood pressure, observed at 15 min intervals, continues to decline during the resuscitation hour. Blood pressure readings have been taken during the course of transfusion after every 540 ccm of blood or plasma transfused. Table I sets out the observed results and a detailed analysis shows that a rise of 10-20 mm Hg is obtained after each 540 ccm transfused; the average figure for the series for each successive bottle up to five being 19.1, 11.6, 16.4, 18.3 and 16.7 mm. This table in conjunction with table II suggests that in order to obtain a systolic blood pressure of 100 mm Hg or over it was necessary to transfuse not less than 50% of the calculated blood loss which may amount to 1000-3500 ccm in severe cases of secondary shock. Coincident with this improvement in blood pressure there was a striking amelioration of other symptoms. The behaviour of the pulse emphasised the unreliability of this factor for assessing improvement. In a series of observations of pulse rate before and after each 540 ccm bottle it was found that after twenty-one bottles the rate fell, after twenty it rose and after four it remained unchanged. Transfusion seemed to produce a fall of rate in those in whom it was initially rapid and vice versa. The general re-



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sponse to transfusion, and particularly in the blood-pressure, which appears to rise quantitatively with the amount transfused, has been a constant feature of our cases.

The value of blood-pressure determination has been emphasised by observations on cases in whom there has been no external evidence of severe loss of blood but detailed investigation has shown that such loss has taken place. Case 16 illustrates this point. The external injuries in this man of 64 were a simple fracture of one arm, two fractured ribs and a compound fracture of the femur with a small wound. Five 540

TABLE 1.—RELATION BETWEEN RECOVERY OF BLOOD-PRESSURE AND VOLUME TRANSFUSED

Case No.	AGE	Initial pulse-rate	Initial B.P.	B.P. after pints					Time taken (min.)
				1	2	3	4	5	
1	00	Un	Un	40/Un	60/40	80/50	105/55	..	65
2	20	86	80/30	70/60	80/75*	95/75*	..	..	80
3	20	82	40/30	70/40	80/45	100/55	Bl.	..	80
4	20	9	60/30	N.R.*	115/65*	..	..	..	20
5	20	155	70/Un	N.R.	N.R.	120/70	..	..	80
6	23	120	75/60	105/80	120/90	..	..	..	15
7	30	Un	95/60	100/65	105/70	..	..	..	45
8	29	Un	60/40	70/Un	90/55	115/75	..	..	75
9	16	117	80/55	95/70	95/70	110/75	..	..	77
10	26	130	70/55	100/50	125/N.R.	..	..	..	105
11	28	Un	70/40	90/50*	Bl.	..	..	..	..
12	50	58	85/65	110/80	120/85	..	..	..	80
13	30	140	00/30	80/50	100/60	..	..	..	40
14	48	Un	Un	N.R.	N.R.*	80/40	120/60	..	140
15	56	101	50/35	70/50	85/55	105/65	..	..	41
16	04	92	50/Un	55/Un	70/50	85/50	100/65	95/80	60
17	22	110	85/70	100/85*	..	..	..	..	15
18	18	Un	50/35	80/45	95/60	115/70	..	..	80
19	19	Un	Un	40/Un	N.R.	N.R.	N.R.	95/1*	115
20	38	Un	90/60	120/60	..	..	..	..	20
21	28	Un	80/7	60/1*	80/1*	N.R.	110/70	..	74
22	20	70	55/1	80/1	80/1	70/40	85/40	100/60*	100
23	52	86	60/40	N.R.	145/80	..	..	..	20
24	25	144	70/50	85/65	100/70	105/80*	..	..	60

Un = Unrecordable.

Bl. = Bleeding.

N.R. = Not recorded.

P.Bl. = Probably bleeding.

All transfusions were of citrated plasma except those marked \* where citrated blood was given.

c.cm. bottles were required during the resuscitation period and one more during operation to raise the blood-pressure to 100/55. This patient died 2½ days later from postoperative bronchopneumonia. At autopsy it was found that the estimated loss to the circulation could be accounted for as follows: swelling of arm and thigh 1200-1500 c.cm., hæmothorax 200 c.cm., hæmoperitoneum 250 c.cm., retroperitoneal hæmorrhage 800 c.cm., external loss at time of injury ?, total 2600 c.cm.+. In all cases seen by us it has appeared that the loss of blood-volume can be accounted for by external loss and by extravasation into the injured area. In no case has there been any evidence to suggest loss of plasma in regions remote from a seat of injury.



The volumes transfused (tables I and II) concern the amount necessary to relieve secondary shock prior to operation. It must be remembered that delay in operation after resuscitation may be associated with deterioration in general condition first from continued blood loss and secondly from excretion of the citrate portion of the transfused plasma or blood. Resuscitated patients should be regularly observed, and if necessary transfusion should be continued during the period of delay. Furthermore, most cases suffer hæmorrhage at operation. No less than 15 of our 24 cases required transfusion during the operation itself.

In general we have concluded that the amount to be transfused should be governed by the blood pressure response on which a watch should be kept during any delay as well as during operation. As to rate we have formed the opinion that the first two 540 c cm bottles should be administered rapidly, each bottle occupying about 15 min. Further amounts, except when the blood pressure is dangerously low (75 mm or less), should be given at a slower rate and be governed by clinical judgment. Transfusion with a blood pressure in the region of 100 mm Hg should be continued as a drip allowing a rate of one bottle in 3-4 hours. This last procedure is a good safety measure to tide over any delay in operation while the transfusion, administered by cannula, can accompany the patient to the theatre and then be speeded up if there is any sudden hæmorrhage or rapid deterioration in general condition.

#### **Hæmatological Aspect**

Of our 24 cases 9 have been investigated hæmatologically, some more completely than others, 8 have been sufficiently examined for the serial hæmoglobin or hæmatocrit determinations to permit of calculation of the blood volume at the beginning of treatment by the method described by Bushby, Kekwick and Whitby (1940). When the blood volume is known a shrewd estimate of the blood loss can be made by assuming an approximate normal blood volume of  $5\frac{1}{2}$  litres for a man and 5 litres for a woman. Table II shows that it is possible to sustain an acute loss of as much as  $3\frac{1}{2}$  litres of blood and yet survive provided that reasonable restoration of blood volume is carried out quickly and adequately. There can be little doubt that if these cases had suffered the delay in treatment which is almost inevitable with battle casualties most of them would never have reached a dressing station alive. The series provides examples of both the accuracy and the fallacy of the method for estimating blood volume. As to accuracy, case 15 was examined by consecutive hæmatocrit measurements of venous blood and estimations of the hæmoglobin content of capillary blood, the blood



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volumes calculated from these different angles were close—3.9, 4.0, 3.8, 4.1 litres respectively. Fallacy is well shown by case 16 where an autopsy two days later made it clear that he was actively bleeding at the time of investigation. Continuance of bleeding renders the calculation inaccurate, biasing the result towards underestimate of blood-loss in direct proportion to the amount of bleeding. From the clinical aspect there can be no doubt that continuance of bleeding is the commonest cause of failure to affect a rise in blood-pressure despite adequate transfusion. Table II sets out the calculated blood-loss, the total and protein fluid restored to the circulation, and the effect of this on the blood-pressure. The results show that when the calculated blood-loss is restored to the extent of 50% or more the effect on the blood-pressure is usually satisfactory. These hæmatological results therefore confirm the accepted clinical belief that transfusion should continue until blood-pressure has been satisfactorily restored. But they also provide a valuable check on clinical impression. For example, case 16 shows that when the calculated blood-loss is disproportionately small in relation to the amount of fluid necessary to restore blood-pressure, continuous unrevealed bleeding should be suspected. There are also other, perhaps uncommon, causes of a sustained low blood-pressure in a wounded man besides reduced blood-volume. The simple hæmatological check combined with good clinical judgment can prevent such cases from having a gross excess of fluid transfused in an effort to restore blood-pressure, so avoiding the danger of pulmonary oedema.

Table II analyses the fluid administered in terms of its protein content—that is, of that portion of the fluid which will remain in the circulation, in contrast to the crystalloid portions which are invariably excreted fairly quickly. The results show the effect on blood-pressure up to the end of the resuscitation period. The importance of maintaining the good effect during the operation period has already been stressed. For this permanent result only the protein fraction can be considered effective. Hence it is essential that the transfused protein fraction should be not less than 50% of the fluid lost and preferably more, bearing in mind that with Army Blood-transfusion Service plasma of every 7 pints transfused 2 are lost as crystalloids. The experimental results of Magladery, Solandt and Best (1940) showed that a protein replacement of at least 40% was required when treating hæmorrhagic shock with serum.

The results shown in table II provide some suggestive facts concerning the phenomenon of hæmoconcentration. There is in the first place no glaring evidence that this is at all marked in cases not suffering from



Our results justify the conclusion that reduction in blood volume demands a reasonably quantitative replacement of protein fluid if a permanent improvement in condition is to be obtained and maintained through a perhaps severe operation. In some cases the amount of fluid required is almost unbelievably large but with each successive pint transfused there should be an appreciable rise in blood pressure of 10-20 mm Hg. If this does not occur continued bleeding should be suspected. Nevertheless over-enthusiasm for quantitative replacement has its dangers. An overfilled circulation is almost as great a menace as one which is dangerously emptied. When hæmatological tests can be performed these supply a valuable check on the blood pressure readings which should whenever possible never be omitted. In the absence of blood pressure readings attention should be paid to the volume of the pulse rather than to the rate. Our impression is that 2 pints can be administered quickly without risk to a case of secondary shock with a blood pressure below 100 mm Hg. If this produces the anticipated rise in blood pressure more can be administered with safety though if the clinical condition has equally improved the rate of administration can be judiciously slowed. But if there is no improvement in blood pressure with 2 pints quickly administered and continued bleeding is neither obvious nor likely a short time should be allowed for warmth and fluid by mouth to bring about that later improvement in blood pressure which a number of cases appear capable of effecting. This is a better practice than continuing with a large rapid transfusion which carries with it a danger of pulmonary oedema if the circulation is overfilled. The rate of administration after the first 2 pints requires sound clinical judgment. But whenever there is clear evidence of gross loss of blood an approximately quantitative replacement should be aimed at.

#### Summary

In observing 24 cases of secondary shock a sustained and serious fall in blood pressure in spite of simple resuscitation procedures has been found to be the one reliable clinically measurable criterion of the severity of the condition. The pulse rate is unreliable.

Simple hæmatological investigations combined with plasma transfusion provide a helpful check on deductions made from blood pressure readings with regard to the amount of fluid that needs to be transfused.

As a rough rule a rise of 10-20 mm Hg can be anticipated from every 540 ccm transfused provided that bleeding has ceased and that no other causes of loss of circulatory fluid are operating.

Plasma and blood are equally effective for restoring blood volume.



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With large transfusions 1 pint in 3 may, with advantage, be blood.

An approximately quantitative replacement of lost fluid is required. At least half of this should be protein fluid, otherwise the restoration of blood-pressure will be only temporary and an operation will not be well borne.

Transfusion should continue during any delay before operation as well as during operation, especially if more blood is likely to be lost at that time.

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# ANAESTHESIA IN WAR CIRCUMSTANCES

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While it is evident that the general principles of anaesthesia are not affected by the circumstances of war, it is equally evident that it is our duty assiduously to seek those means in anaesthesia which are especially suited to the exigencies of battle, and I hope to show that although men of the fighting services are of necessity exceptionally fit before an engagement, they may frequently be most urgently in need of the best attention known to anaesthesia after the conflict. While our subject cannot be exhausted in this discussion, it may be treated briefly, as we consider the circumstances variously obtaining before, during, and after anaesthesia, always mindful of the axiom that whatever is done should suit the general condition as well as the surgical requirements of a given individual.

*Slight injuries*—Wherein there is little or no shock, the subject of lesser lesions will have received promptly for his pain, an opiate, with which it is well to give scopolamine to enhance its action, dispel fear and cause amnesia. If much more than an hour elapses before the start of anaesthesia, these drugs may be administered again. And now, the choice of the anaesthetic is from among those of 'local' and 'general' procedures. Usually, in this class of case, in which muscular relaxation is not particularly required, it will suffice to use local infiltrations or "nerve block" injections of drugs like procaine, inhalations of nitrous oxide, cyclopropane, vinyl ether or ethyl ether, or, intravenous administrations of one of the shorter acting barbiturates, such as pentothal. The selection will be influenced by the number of cases to be done, the number of anaesthetists and the extent of the surgical facilities. The time factor may be important.

*Severe injuries*—Casualties manifesting shock are to be handled with the greatest circumspection and with the least possible surgical intervention until the state of the blood circulation is restored. Any such case must be actively treated for shock until he has recovered fairly well from the early physical condition of depression, before an operation is attempted. During the interval, to conserve energy one may give small doses of opiates, such as morphine and scopolamine with vigilance in regard to respiratory depression, one gives supporting intravenous fluids, until the pulse rate decreases and the blood pressure goes up considerably, and one applies heat for the restoration of body temperature. So soon as these circumstances have been rendered relatively stable as evi



denced from frequent observations on the character of the breathing, the rate of the pulse and the degree of the blood pressure; so soon as these three seem to be on a satisfactory scale in relation to one another, the patient may be considered ready for operation.

The question of anaesthesia now presents itself, and at once it may be said that, with an adequate personnel in a well equipped unit, it is not difficult to decide on what anaesthetic drugs to use and what procedures to employ. Let us select impartially from among the drugs at our disposal as well as from the methods of their administration, with a view to their appropriateness to the conditions of the man about to undergo an operation. In pre-operative medication, it is customary to use one or more of the sedatives; morphine, dilaudid, a barbiturate such as nembutal or pentothal, avertin, and scopolamine or atropine. Usually, it matters little how these are combined, only one tries to give just enough to produce the desired effects, that is, completely to obnubilate the mental faculties, and so lessen the shock which comes of fear; effectively to inhibit secretions, and so avoid respiratory obstruction; considerably to reduce the amount of general anaesthetic which may be used; and, commendably, to cause the induction of anaesthesia to be much easier.

Looking at the matter in another way, one tries to give just enough of these drugs to produce the desired effects without too much interference with the respiratory movements, too much depression of the circulation, without disturbances to the oxidation-reduction systems. Lest we forget, those braves who come to us, as Homer said, "from out the slaughter, blood, and battle-din", from fighting for us in the "fire, and water, and earth, and lofty ether unbounded", in the words of the pre-Socratic philosopher, Empedocles; these braves ones are none the less subject to emotional impression, none the less susceptible, perhaps inconsciously, to fear, to anxiety, to apprehension. Sedatives soon succeed in quelling such storms of feeling.

For cases of severe injuries, the selection of anaesthetics and of the methods of their administration is done from those belonging to the greater groupings of anaesthesia, namely: regional anaesthesia, that is, local or spinal; and general anaesthesia, whether inhalation or intravenous. I shall consider the anaesthetic materials jointly, with means of their administration, and try to show their suitabilities to the surgical procedures on patients suffering from this type of lesion.

*Regional.*—Procaine, metycaine, nupercaine, and pontocaine are the drugs just now in favor for producing regional anaesthesia. Virtually, they cause little, if any, impediment in the vital processes. Their employment should, therefore, be encouraged. And although, in execution,



local infiltration, field block, the different forms of nerve block, and spinal anaesthesia are found by a large number of surgeons to be tedious and time consuming, yet as these have become in many instances part of the duties of the anaesthetist—the instances are increasing—in consequence, not only is the surgeon freed of the bother but, through increased individual experience, the dangers have become almost negligible.

So long as preliminary sedation has been made complete, the local and block types of anaesthesia may be considered almost ideal for operations on the head, neck and extremities, and even in the abdomen as well as the thorax, on those rare occasions when spinal anaesthesia may not be carried out on account of the inadvisability of moving the patient. The advantages of spinal anaesthesia are very great, especially on account of the muscular relaxation and the excellent recovery. Digby Leigh and I<sup>1</sup> have shown that, with the exception of blood dilution, the many changes which are apt to take place from general anaesthesia do not appear in spinal anaesthesia. Let it be remembered that some of these changes in metabolism may seriously impede the course of recovery in the patient who suffers some extensive debilitating lesion.<sup>1</sup>

At present I favor the use of percaïne for spinal anaesthesia as it lasts longer than any other of its kind, and the Etherington Wilson technique for its administration<sup>2, 3</sup> as with the sitting posture much less of the drug is required. Someone will object to the sitting up of a morphinized patient, but it has been found that blood pressure and pulse rate change very little. It would seem that spinal anaesthesia is only contraindicated wherein the fall in blood pressure, which it frequently causes is to be feared, as in cases of marked hypertension and advanced cardiovascular disease. Such are not likely to be met among war casualties from the personnel of the fighting forces, but they are being met among those from civil life in the present conflict. As intimated before, there will be much less fall in blood pressure if relatively large quantities of depressant drugs have been given prior to the production of all forms of regional anaesthesia so thoroughly to subdue the cerebral cortex as utterly to bemuddle its organs of thought.

*General.*—Being a little uneasy lest the devotees of inhalation anaesthesia say that I have over indulged spinal and the like, let me hasten not to recant, but to say enough so that they may not think me guilty of apostasy. It should be evident that the intravenous method is not advisable for other circumstances than those of minor surgery, for war conditions, the giving of such a drug as pentothal intravenously for an operation of more than twenty minutes, or to administer it fractionally, might well be objected to on the ground of too much detail.



With regard to inhalation anaesthesia, although ether still has a definite place in surgery, although it may be used with relative ease and safety by those who are not too well experienced, and although, when better equipment is not at hand, it is quite permissible to give ether by the "open drop" method; yet nowadays all surgical centres will have an adequate number of anaesthetic machines from which nitrous oxide, cyclopropane or ether may be administered alone or with one another. The high accomplishments of inhalation anaesthesia of late years are the employment of cyclopropane,<sup>9</sup> the absorption of carbon dioxide,<sup>7</sup> and the closed intratracheal technique.<sup>8</sup> The advantages of cyclopropane are already too well known for me to be prolix in the matter, but it may be said that there are two splendid combinations: one of avertin by rectum with cyclopropane, following, by inhalation, the other of pento-thal by vein,<sup>4</sup> with cyclopropane by inhalation immediately after. In each instance a smaller-than-usual dose of the first drug is given, the production of full anaesthesia by cyclopropane is done much more easily than ordinarily, and there would seem to be perhaps some salutary synergistic action. In busy periods, however, the giving of avertin takes too much time. The removal of carbon dioxide from the expired air permits in the same case the continued and repeated use of the anaesthetic materials. The closed intratracheal method precludes respiratory obstruction; obviates interference with some surgical procedures, such as in operations about the head, neck and chest; gives absolute assurance of a plentiful supply of oxygen directly to the lungs; affords quieter breathing and a softer abdomen, although narcosis is not profound; and supplies the ready application of Guedel's method of artificial respiration.

So much then for a cursory account of the circumstances prevailing before anaesthesia essential to the treatment of injuries during war. It may serve to indicate the extent of our selection. Neglecting for the nonce the lesser ailments, let us follow a little the course of anaesthesia during operation for a major lesion. Having, in a given individual, chosen the drugs and the methods of their administration, and having produced the required degree of narcosis, it becomes the duty of the anaesthetist carefully to manage its progress. Here let me say that there is no reason why the quality of anaesthesia as well as the ability of the anaesthetists should not be just as high and as great for surgical units of war time as they may be under any other circumstances. The best is none too good for those who fight for us. Before the operation is started the intravenous administration of fluids ought to be begun and continued throughout at a rate suitable to the state of the blood pressure and character of the pulse. Of the clear solutions, glucose should be used in



the regional cases, and saline only should be given to the cases of general anaesthesia for the simple reason that in these there is invariably a hyperglycaemia at the time. Either may be replaced by blood or plasma very readily.

To this fluid stream may be added without delay either analeptic and resuscitating or sedative drugs momentarily. Restlessness, which occasionally occurs during regional anaesthesia, can be controlled promptly by the injection of a morphine solution into the intravenous tube. Analeptics, too, may be given in this way. Concerning these, I am firmly of the opinion that they should not be used routinely nor in anticipation of shock. They tend to stimulate the central nervous system and to reverse the effects of sedatives, for example, in spinal anaesthesia, when morphine and scopolamine have been given especially to produce their desired actions, I have found that these beneficial effects will be definitely minimized by the administration of a mixture of ephedrine and posterior pituitary extract. Why wantonly undo that which was deliberately done with good reason? It has been shown that analeptics are not needed in spinal anaesthesia by the Etherington Wilson technique, even in upper chest surgery, in about 60 per cent of cases.<sup>2</sup> A most remarkable synergistic effect takes place when posterior pituitary (pitressin) is given along with the ephedrine.<sup>6</sup> The one supplements and enormously enhances the power of the other, the result being more effective than larger individual quantities of these drugs in restoring blood pressure and respiration and in abolishing general collapse.

Usually, when it is deemed advisable to use these materials, their hypodermic administration will suffice. The intravenous avenue is not recommended unless the patient is very far gone. This form of stimulation is seldom needed in general anaesthesia, indeed, with cyclopropane it is contraindicated. When modern machines are used a liberal supply of oxygen is assured during inhalation anaesthesia, but in the spinal procedure one is well advised regularly and actively to administer oxygen on account of the depressed breathing, the sluggish circulation, and the dilution of the blood, in other words, on account of the impoverished respiratory exchange and the reduced oxygen carrying power of the blood.

The immediate after care of a patient just operated upon is not only extremely important but supremely so to the anaesthetist. It becomes him to have a hand in the matter, for by how much the more the possibilities are considered, by so much the more will sequelae be checked at their source or, at least, be caught in incipience. After operation for a severe injury the patient should be moved with the greatest gentleness, particu-



larly in regard to the horizontal plane, and any desired change in position ought to be made very gradually. This significance concerns the circulation chiefly. Intravenous supporting fluids are to be given as frequently as indicated and to these may be added analeptic drugs, or pain relieving drugs as required. Oxygen therapy should be kept up as long as respiration and circulation are depressed, this implies that the upper respiratory passages must be perfectly patent and that the gas be made moist. To lessen the likelihood of post-operative pulmonary complications, there should be some change made in the patient's position every hour, he should be encouraged to breathe forcefully every hour, and carbon dioxide may be added to the oxygen occasionally. In order that invaluable information be not lost, and for the sake of uniformity, each surgical unit should be obliged from headquarters to keep records of each case, along standard lines, of all that specially pertains to anaesthesia.

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# BLOOD SUBSTITUTES IN THE MILITARY SERVICE

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The possibility of transfusing blood from one human to another has captured the imagination of medical men for the past four centuries. The development during our times of successful methods for accomplishing this feat is another monument to the untiring effort of medical science. The use in World War I of fresh whole blood and preserved blood and preserved blood as advocated by Robertson<sup>1</sup> paved the way for the general adoption of blood transfusion as a measure of proved therapeutic value. At the present time blood transfusion is a standard procedure in civilian hospitals and in the fixed installation of the Medical Corps of the Army.

The recent work of DeGowin<sup>2</sup> and his associates on the transportation and use of preserved blood raises the question of its efficacy for use by military forces in the field under combat conditions. Preserved blood can be used if refrigeration can be made available but under actual combat conditions this requirement is considered to be insurmountable. It is believed however that whole blood and preserved blood can and should be made available as far forward in the Theater of Operations as the evacuation hospital.

Realizing the difficulties of supplying blood for the treatment of casualties in the combat zone it became apparent that colloidal fluids other than blood would have to be developed and used for this purpose.

No less prodigious and equally as intriguing as the work on blood transfusion are the developments that have taken place in the field of blood substitutes and the use of blood derivatives during the past twenty five years. The quest for substitutes for whole blood during World War I led investigators to a study of gelatin and gum arabic. Due to the difficulty of purifying the former, its use was short lived. Acacia first used extensively by Bayliss<sup>3</sup> in 1916 although not a physiological substance proved to be of value in restoring colloidal osmotic pressure in shock and other conditions of depleted blood volume. In recent years a purified form of acacia has been made available and it is still used to restore blood pressure when whole blood or blood substitutes cannot be procured.

The recognition of blood plasma and serum as effective agents for



the replacement of depleted blood volume and blood proteins has made a deep imprint in the field of medicine. Although plasma has but recently been accepted as an adequate replacement fluid, the suggestion that plasma be used in place of whole blood dates back over two decades. As early as March, 1918, Captain Gordon R. Ward,<sup>4</sup> R.A.M.C., pointed out that one of the chief troubles with whole blood transfusions is that the erythrocytes of the donor may be hemolized by the recipient's plasma. He made the observation that death from hemorrhage is not due to lack of hemoglobin but loss of fluid and therefore the treatment resides in the replacement of the depleted fluid. For this purpose he suggested the administration of citrated plasma which can be preserved easily and injected safely. This plea remained unheeded for nearly twenty years.

Rous and Wilson<sup>5</sup> in 1918, while studying the effect of hemorrhage in animals, used plasma to replace the blood loss. Based on their results they stated that the replacement of red blood cells is not essential because even in severe hemorrhage a sufficient number of erythrocytes remain to support life. The loss of blood volume is the important factor.

Mann,<sup>6</sup> in 1918, used blood serum for the treatment of surgical shock produced experimentally in dogs. He observed that the intravenous injection of homologous serum produced results in the treatment of experimental shock equally as effective as any method at his disposal. Best results were obtained with relatively large doses of serum. Mann stated prophetically that homologous serum might be of value where serum could be kept and whole blood could not be obtained.

Interest in plasma as a blood substitute for clinical use was revived in 1936 by Elliott<sup>7</sup> when he suggested the use of untyped serum and plasma for the treatment of surgical, obstetrical and traumatic shock where transfusions are indicated. He pointed out that the need for replacing depleted blood volume in shock is more important than supplying additional red blood cells, as the maintenance of osmotic pressure is a function of the plasma proteins. Elliott also stated that liquid plasma if properly prepared in a "closed system," could be preserved for long periods and administered safely.

The experimental and clinical use of liquid plasma and serum by Mahoney,<sup>8</sup> Bond and Wright,<sup>9</sup> Elkington,<sup>10</sup> McClure,<sup>11</sup> Strumia,<sup>12</sup> Best and Solandt,<sup>13</sup> and Levison,<sup>14</sup> to mention a few, has established the efficacy of these fluids as adequate agents for the treatment of traumatic shock, burns and hemorrhage. In 1941, Strumia<sup>15</sup> advocated citrated blood plasma without cross matching and in the same year Kekwick,<sup>16</sup>



et al, after using plasma and serum for the treatment of shock and hemorrhage in air raid casualties in England, concluded that these fluids are equally effective in injuries of this type

Although liquid plasma has proved to be an effective fluid for restoring blood volume and can be preserved for many months, it has been shown that the labile substances undergo changes when stored in the liquid state. In order to preserve plasma with as little change in its constituents as possible, methods of drying it were developed. Shackell,<sup>17</sup> in 1909, first described the desiccation of biological substances by sublimation from the frozen state. The principles of drying as outlined by him have been followed generally in developing equipment for the preparation of dried plasma. Plasma dried from the frozen state and properly sealed can be preserved for at least five years and can be restored to the liquid state quickly by the addition of distilled water. Properly prepared dried plasma retains most of its labile substances and thus provides a very satisfactory protein fluid for the treatment of depleted blood volume and hypoproteinemic states.

In May, 1940, when the tide of conflict was turning in favor of the Axis powers, it became apparent that we were facing a national emergency. In order to provide the best medical service possible for the rapidly expanding forces of the Armed Services, the Surgeons General of the Army and Navy requested the help of the Division of Medical Sciences of the National Research Council. As a result of this request committees were appointed to act as medical advisors to the Army and Navy. One of these groups, known as the Subcommittee on Blood Substitutes was asked to determine the most acceptable blood substitutes and methods of supplying them to the Army and Navy. As a result of the work done by the members of this committee, it was recommended that dried plasma be used as the substitute of choice for the treatment of burns, shock, hemorrhage and other hypoproteinemic states. Following this decision it became necessary to develop complete equipment for the packaging of the dried plasma, distilled water and intravenous assembly so that the plasma could be administered in the field under combat conditions and aboard ship in naval engagements.

As a result of work carried on by the Subcommittee on Blood Substitutes and representatives of the Army and Navy a plasma package has been developed which is considered to be practical for field use. In order to produce a package for universal use by the Armed Services it was necessary to take into consideration size, keeping quality of the dried plasma, distilled water and rubber tubing and also to provide a complete set of equipment for administration. It has been established



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that plasma dried from the frozen state can be preserved for five years if properly stored in a flame sealed glass container. However, due to the fragility of the glass seal and the large package required when this closure is used it was necessary to utilize a rubber stopper closure. By placing the rubber stoppered bottle in a metal can under a vacuum, adequate sealing can be accomplished. In order to preserve the rubber tubing of the intravenous assembly and prevent deterioration from oxidation, the tubing is packaged in another can with the bottle of distilled water under an atmosphere of nitrogen. With this type of packaging it is believed that the plasma and rubber tubing can be kept safely for a five year period.



FIG. 1.—Contents of the complete package.

A description of the standard Army and Navy Package of Human Dried Plasma follows:

The completed package (Fig. 1) consists of two 400 cc. bottles stoppered with vaccine type rubber stoppers; intravenous equipment in sealed metal cans and packaged in a tape-sealed water-proofed fiber-board box. One bottle (Fig. 1) contains the dried plasma obtained from 300 cc. of citrated plasma and is sealed under 29 inches of vacuum. This bottle is fitted with a cloth tape to be used for suspending it in the inverted position while the plasma is being injected. The other bottle contains 300 cc. of sterile pyrogen-free distilled water sealed without vacuum. The intravenous equipment consists of an airway assembly and an intravenous set (Fig. 1). The airway assembly consists of nine inches of rubber tubing with a needle attached on it for insertion into the rubber stopper and a cotton filter on the other end. The intravenous set is made up of forty-eight inches of rubber tubing which contains a glass cloth filter for filtering the plasma as it is administered. At the end of the tube is an intravenous needle which connects the set



to the plasma bottle. The bottle containing the distilled water is sealed in one can which is filled with dried nitrogen. The bottle containing the dried plasma along with the intravenous needle, clamp and double ended needle used for adding the distilled water to the plasma is placed in the second can which is sealed under 25 inches of vacuum. The instructions for the preparation and the use of this material are lithographed on the can containing the plasma bottle (Fig. 1). Both cans together with a questionnaire for recording data on the use of this unit are packaged in a tape-sealed water-proofed fiberboard box (Fig. 2). This questionnaire is to be returned to the Army or Navy Medical Centers depending on the Service using the material. Statistics will be



FIG. 2—Standard army-navy package of dried human plasma.



FIG. 3—Cans removed from box with cord



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compiled from these reports. As the cans fit very snugly in the box a string is placed around the cans to facilitate the removal of them (Fig. 3). The finished package (Fig. 2) has on one end a label of the biological firm processing the plasma and on the other end a Red Cross label showing that the blood from which this plasma was made was furnished by volunteer Red Cross donors.



FIG. 4.—Reconstitution of plasma by connecting the bottles with a double ended needle.

The plasma is made ready for use by inserting the double ended needle in the stopper of the bottle containing the distilled water. This bottle is then inverted and the other end of the needle is plunged into the stopper of the dried plasma bottle. The vacuum in this bottle causes the water to flow in and the plasma goes into solution in about two minutes. When the water does not flow into the plasma bottle freely, the needle of the airway should be inserted into the stopper of the water bottle (Fig. 4). This will allow displacement of the water with air and thus speed up the flow of water. The airway and intra-



venous set are then connected to the plasma bottle (Fig 5) and the plasma is ready to administer

The package as outlined above has been approved by the National Research Council, by the National Institute of Health and adopted for use by the Army and Navy. Contracts have been made with several commercial biological houses to prepare 200,000 units, each containing

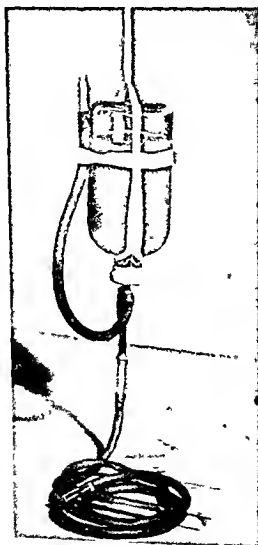


FIG 5—Reconstituted plasma ready for administration

250 cc of dried plasma, for the Armed Services. The blood required for the production of this plasma is being obtained from volunteer donors by the American Red Cross. Bleeding centers have been established in densely populated areas throughout the country. As the blood



is collected it is transported under refrigeration to the nearest processing firm. After it is dried the plasma is packaged and shipped to the Medical Supply Depot in Brooklyn for distribution. With this program as outlined it is anticipated that a large reserve supply of dried plasma will be made available for the Army and Navy within the ensuing year.

Experimental work on the use of plasma and other newer blood substitutes is being carried on at the Army and Navy Medical Centers. Liquid plasma is being prepared at both centers in order to determine its effectiveness and the length of time that it can be preserved. Liquid plasma has been used extensively in recent months on the Surgical and Medical Services at Walter Reed Hospital. Approximately 150 bottles of liquid plasma prepared at the Army Medical School have been administered to patients at Walter Reed. There have been two mild reactions. Liquid plasma is also being prepared at the Naval Medical School<sup>18</sup> and shipped unrefrigerated to twenty Naval Hospitals within the continental limits of the United States. Carefully prepared, sterile, expendable, cellophane intravenous sets containing glass cloth filters are enclosed for use with approximately one-half of the bottles of plasma sent out. The hospitals furnish their own intravenous equipment for the remainder of the bottles. Thus far 785 units of plasma have been sent out and the results following administration have been reported on 500 of these units. There have been eight reactions of a pyrogenic nature, seven of which were mild and one severe. No reactions occurred when the expendable cellophane sets were used.

The tests carried out thus far at the Army and Navy Medical Centers serve to corroborate the results of other investigators that liquid plasma can be preserved for 9 to 12 months without refrigeration and can be administered easily and safely. Liquid plasma provides a colloidal solution of proteins which is effective in replacing depleted blood volume.

At the present time most of the liquid plasma at the Army Medical School is maintained in the frozen state in a regulation ice cream cabinet which provides a temperature of  $-20^{\circ}\text{F}$ . In the frozen state plasma can be preserved indefinitely with practically no change in the labile constituents.<sup>19</sup> When the plasma is to be used, it is thawed rapidly by placing the bottle in a  $37^{\circ}\text{C}$ . water bath. Thawing requires about twenty minutes. If thawed in this manner there is no precipitation of the protein constituents. Plasma treated in this manner can be administered at once or kept at room temperature for several weeks before it is used. By freezing and thawing as outlined above it has been possible to freeze and thaw plasma eight times<sup>18</sup> and then administer it without ill effects.



In an effort to provide a smaller package of plasma to be used by the Armed Forces it was proposed that concentrated plasma be given a clinical trial. This was done at the Army and Navy Medical Centers and the conclusions based on these studies were that four times concentrated plasma was not as effective as normal plasma in the treatment of traumatic shock. This appears to be especially true in dehydrated patients. In cases of this type it is felt that the replacement of blood volume with normal plasma is essential. These findings are in accord with those of Mahoney<sup>20</sup> and Levinson<sup>21</sup>. As a result of this study and similar experiences by other investigators it was recommended by the Subcommittee on Blood Substitutes that the Army and Navy use normal plasma and not concentrated plasma in the treatment of traumatic shock.

#### Newer Blood Substitutes

Although human blood plasma and serum have proved to be adequate therapeutic agents for the treatment of traumatic shock, burns and hyperproteinemic states, investigations are being made in an effort to find substitutes more readily available and equally as effective as human plasma.

*Human Albumin* It is possible to separate the various fractions of blood plasma. Human albumin prepared by Cohn<sup>2</sup> has been given a limited clinical trial and the results thus far are encouraging. Albumin makes up 65% of the plasma proteins and it provides approximately 85% of the osmotic pressure exerted by the blood. It has been administered in 30% solutions without reactions and can be preserved in the liquid state without refrigeration. One hundred cc of 30% albumin exerts approximately the same colloidal osmotic pressure when injected intravenously as 1 000 cc of whole blood. It is therefore possible to package it in a small unit ready for immediate use.

Experimental and clinical trials have furnished encouraging evidence that albumin is effective in restoring blood volume in shock. However, when dehydration is associated with shock, it is essential that water by mouth or electrolytes parenterally be given in conjunction with the albumin.

Human albumin has been administered at the Army and Navy Medical Centers and although the results were satisfactory, further experimental and clinical data must be obtained before albumin can be unconditionally accepted as an adequate blood substitute for use by the Armed Services.

*Bovine Plasma* Plasma derived from cow's blood has been given a thorough clinical trial by Wangenstein<sup>22</sup>. The incidence of reactions from bovine plasma injected intravenously has been very high and the



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reactions have frequently been severe. The results reported preclude the use of bovine plasma as a satisfactory blood substitute.

*Bovine Albumin:* Attempts are now being made by Cohn and his associates to produce a purified bovine albumin. Janeway<sup>24</sup> has reported on the clinical use of this material and states, "It is too early to evaluate work of this type but it represents an important approach to the problem of providing cheap and readily available blood substitutes."

*Isinglass:* Taylor and Waters<sup>25</sup> have recently reported the use of isinglass as a blood substitute. Isinglass or fish gelatin is prepared from the fish bladder. These workers have shown that this material is effective in restoring a normal blood pressure in dogs following hemorrhage produced experimentally. Further experimental and clinical data must be obtained before the effectiveness of this agent as a blood substitute can be evaluated.

*Pectin:* Hartman<sup>26</sup> and his associates have published a preliminary report on the use of pectin as a blood substitute in the treatment of shock. Pectin is a nontoxic, nonantigenic, colloidal carbohydrate having a relatively high molecular weight. When injected intravenously it is eliminated by the kidneys in approximately 72 hours. The experimental and clinical studies that have been made on pectin indicate that it is effective in the treatment of shock. Exhaustive studies on the use of pectin are indicated before it can be accepted as an adequate blood substitute.

### Summary

Developments concerning the use of blood derivatives and blood substitutes have been discussed.

A description of the Army and Navy Standard Package of Dried Plasma has been presented.

Human plasma is considered to be an effective therapeutic agent in treatment of traumatic shock, burns, hypoproteinemic states and for the emergency treatment of hemorrhage.

Dried plasma, because of its long preservation period without undue alterations of the protein constituents, its ease of administration and effectiveness in restoring blood volume, is the blood substitute of choice for use in the Military Services.

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## DRAINAGE OF THE PLEURA

By R. C. BROCK, M.S., F.R.C.S.

Although pleural drainage does not afford a subject so dramatic as certain other features of war surgery of the chest, such as the removal of foreign bodies, it is perhaps *more important than any other*. It profoundly influences both *mortality and morbidity*, and is probably the greatest single factor in determining the length of invalidism, which in a mismanaged or unfortunate case may be lifelong. Like the treatment of pleural infection in civil work it can be conveniently considered under three headings: (1) when to drain the chest; (2) the provision of adequate drainage; (3) when to stop drainage.

### *When to Drain the Chest*

Apart from the presence of frank suppuration the question arises as to drainage in less precise circumstances. It is well to remember two guiding principles which are of value in deciding whether or not to drain the peritoneum and which may well be applied to the pleura: (a) is a condition present which the pleura cannot deal with by itself? (b) Is it anticipated that a condition will develop which the pleura will not be able to deal with by itself? We have a shrewd idea of what the peritoneum can deal with by itself, and I am coming to the conclusion that the pleura can deal almost as effectively with a certain amount of contamination, provided (a) the lung is healthy and no fistula is present; (b) no infected foreign body is present; (c) there is no infected chest-wall wound.

A penetrating chest wound other than a small one without haemothorax or pneumothorax of any size should be excised and either sutured, if only a few hours old, or packed open. The question arises as to whether the pleura should be drained in these cases. If the wound is large and with much laceration and contusion, or if there is a retained foreign body or damage to the lung, then the pleura should be drained by means of an air-tight intercostal catheter connected to an underwater seal and left in place for *forty-eight or seventy-two hours*. In fact, the surest general rule to follow is to drain every time. An intercostal catheter in use for two to three days can do no harm, and although perhaps unnecessary in some cases, will be responsible for averting disaster in many others. I have seen undrained cases of this type heal satisfactorily even when a haemothorax was present and had not been evacuated; the deeper layers have healed over and the haemothorax has been successfully treated by aspiration, thus proving that the pleura has been



able to master some contamination at any rate. On the other hand, I have seen an even larger number of cases in which infection has supervened, drainage has been needed, and a long period of disability has resulted. There is no doubt that it is most unsafe not to drain if the pleura has not been sucked clear of blood and serous exudate before the chest wall wound is closed, any such residuum is a dangerous culture medium to leave in the pleura.

Although routine drainage for two or three days is recommended, it is permissible for a surgeon familiar with the chest not to drain in selected cases provided he is able to watch the patient closely himself for at least seven to ten days.

### **Dangers of Suturing Too Soon**

When the first war casualties began to arrive from France we found that many of the chest wounds had been excised (often very incompletely), sewn up tight without drainage even when the lung had been incised to remove a foreign body, and then transported within a few days. Much of our work consisted in taking out stitches, packing open the wound which was the centre of a severe, spreading, sometimes gangrenous, cellulitis, and inserting an intercostal catheter into the infected pleura. Severe or fatal anaerobic infection may occur, and at the very least the patient has to face weeks and sometimes months of slow convalescence from a total pleural suppuration with the lung perhaps completely collapsed and often containing one or more foreign bodies. The catastrophe could have been easily avoided in almost every case if the chest wall wound had not been sewn up tight, but had been left open, and if a temporary intercostal drain had been used.

There is no doubt that these disasters have occurred owing to misunderstanding of the teaching about the treatment of an open sucking wound. It is generally taught, and generally accepted, that these wounds must be closed at all costs. That is quite correct, they must be closed but not necessarily sutured. It is not safe to excise and sew up tight a big wound of the chest wall with lacerated and contused muscles, in the thigh or arm such a wound would not be sutured but would be packed open initially until the risk of spreading infection had passed. It is not possible to ignore a basic surgical principle such as this. The muscles and fascial planes overlying the thorax, far from being immune, are very susceptible to infection, which may rapidly give rise to a severe phlegmon. Unless, therefore, the wound is relatively simple, is completely excised soon after being received, and can be watched personally for at least a week it must not be sewn up. A flat pad should be laid



over it and secured by properly applied firm strapping. Such a wound is closed mechanically, but surgically it is still open. The pleura should be drained, as stated above, for two to three days. If it is then found that the lung is adherent and the deeper layers of the wound are shut off from the pleura the drainage tube may be removed, although careful watch will have to be kept for reaccumulation of effusion, which will need drainage again if aspiration reveals that it has become infected. The parietal wound can, and in fact should, be closed by delayed suture packed open initially until the risk of spreading infection has passed.

The management of a haemothorax may present many difficult problems, but one of the greatest dangers to be on the alert for is the onset of infection. This may not occur until as late as ten to twenty days after receipt of the wound, and may lead to death from anaerobic infection in a patient who had appeared to be almost convalescent. Presumably infection occurs from sloughing of devitalized lung tissue in the track of the missile. Close watch must be kept for the onset of infection; the temperature may be no true guide, but a rise in the pulse rate is significant. The fluid in the chest must be sampled at least every other day, and should be examined at once for evidence of infection. It is not enough to send a specimen to the laboratory. The haemothorax itself is an excellent culture medium, and much information can be obtained by its direct study; when infected the blood may smell, haemolysis occurs, the color changes to a purplish hue, and if a direct smear is examined micro-organisms will be seen. Culture in the laboratory will only confirm these findings. It is most important that samples of fluid aspirated from the chest should be kept by the patient's bed and properly labelled so that they may be available for inspection at any time. It is a common but nevertheless stupid habit to throw valuable evidence of this sort away and not to preserve it for future reference.

Once infection of the haemothorax has occurred drainage is needed. The type of drainage is considered in the next section.

#### **Provision of Adequate Drainage**

In a certain small number of cases pleural infection can be satisfactorily overcome by repeated aspiration of the exudate, but though this minor procedure is occasionally successful it is wrong to put it forward as a safe or standard method of treatment, except to tide over a few days, or two to three weeks at the longest. The same applies to intercostal drainage, which is invaluable as a temporary measure—in fact, is often life-saving—but will allow rapid and safe healing of pleural suppuration in only a few cases. It is a great mistake to imagine that all will go well



and that rib resection can be avoided just because the patient looks and feels better and the temperature has subsided. The fundamental principle of civilian surgery still holds good, that in almost every case of empyema the adequate drainage provided by rib resection is essential to allow perfect healing in the shortest time and with the minimum of disability. To continue with a small intercostal drain for more than a few days is to expose the patient to the grave risk of a chronic empyema. The step of rib resection is a small one, should take only a few minutes, can be performed under local or a short gas anaesthesia, and should be no burden even to a very ill patient.

At the same time it is important not to drain the pleura too early. In war wounds, as in the synpneumonic pleural infections of civil life, there is usually diffuse infection of the whole pleura with no localization. If drainage is performed too early a total empyema results, the lung often remaining collapsed down on the hilum, in others the lower lobe expands more rapidly than the upper lobe, the drainage point is soon shut off, and a large residual or imperfectly drained anterior pocket is left, usually extending to the apex. These cases have been only too common and have proved to be very difficult to treat, they tend to become chronic, take months to heal, and leave the patient with an impaired respiratory function on the affected side. In many it has been almost unavoidable when aspiration has been difficult and unsatisfactory owing to the debris of infected clot, and the patient has been so desperately ill that early intercostal drainage has been needed as a life saving measure. But unless this is the case, tube drainage should be postponed and aspiration persisted in until the pleural infection has become localized to give a true abscess. The aspiration must be performed regularly and efficiently and not infrequently and perfunctorily, by keeping the pleura as dry as possible not only is toxæmia diminished but the ultimate empyema will be a small one and therefore quicker to heal when it can be adequately drained by rib resection.

For the usual posterior basal empyema the best drainage is given by resecting about 3 cm. of the ninth rib just outside its angle. If a lower rib is taken not only is there risk of wounding the diaphragm but in the natural process of healing the ascent of the diaphragm will shut off the drainage hole and may cause a chronic empyema. Similarly drainage too far forward is to be avoided, a tube inserted in the mid axilla or anterior axilla cannot drain the posterior pleural recess efficiently, and a chronic empyema is almost certain to follow. Unless the patient has a pleuro bronchial fistula there is no reason to fear turning him on his good side to resect a rib in the proper place at the back,



## *Drainage of the Pleura*

to try to work with him lying on his back is inefficient and fooling. If a broncho-pleural fistula is present the operation can be performed with the patient sitting up and under local anaesthesia; it is probable, however, that if the fistula is of any size a preliminary intercostal catheter will have been inserted earlier.

It is best to connect the drainage tube to a simple empyema bottle; this enables the pus to drain away cleanly, saving much labour, disturbance, and discomfort from constant changing of pus-soaked dressings, and it encourages expansion of the lung by maintenance of a mild negative pressure.

### **When to Stop Drainage**

The termination of pleural drainage is a most important phase, and may be difficult to assess exactly. When drainage has been used as a safeguard in the presence of a certain amount of pleural contamination it can be stopped in two to three days; but when it has been needed because of an established infection the problem is quite different. There is no doubt at all that mismanagement of the drainage tube or its too early removal is responsible for much unnecessary suffering and a great deal of permanent crippling. Unfortunately the correct management of this phase had been understood during only the last decade or so, and the knowledge is still far too scantily appreciated. This is at once seen if standard surgical textbooks are consulted; it will be found that no correct rule is given as to when the drainage tube should be removed, but only some quite incorrect rule-of-thumb advice such as "after three weeks" or "when the discharge stops" or "when the discharge becomes thin." There is only one safe time to remove the tube, and that is when it is no longer possible to demonstrate a cavity in the pleura. This is a rule that cannot be too widely appreciated or stressed too much. Failure to observe it is responsible for more chronic empyemas than any other single cause.

In the healing of a simple acute abscess, provided drainage is maintained adequately, the walls collapse together and adhere by granulation until the cavity is completely obliterated; the discharge then ceases, the skin grows over, and healing is permanent. The proper healing of an acute empyema is no different: provided adequate drainage is maintained the walls come together (that is, the lung expands; collapse of the parietes is of course avoided by proper exercises) and adhere by granulation—that is, there is progressive symphysis of the visceral and parietal pleurae until the whole pleural space is closed. Then and then only should the drainage tube be removed. The final track from pleura



to skin will close simply and certainly and permanent cure follows. Should the tube be taken out when a pleural pocket still remains progressive and satisfactory healing may follow but it is much more likely that a chronic empyema will occur. Even if the skin heals temporarily a latent pus pocket remains to be a constant source of toxæmia and sooner or later (perhaps weeks or month perhaps many years after) will flare up and lead to recurrence.

The best way to decide the problem of tube removal is to investigate the size and extent of the cavity by a pleurogram—that is radiography after instillation of a radio opaque fluid or oil such as neohydriol or lipiodol. This should be done when it is felt that the cavity has diminished to a reasonably small size from a study of the size shape and disposition of the cavity any necessary adjustment in the size and disposition of the drainage tube can be made. Thus it is usually necessary to shorten the tube in the later stages of healing but it may be shown that not shortening but lengthening is needed if a high up or anteriorly placed loculus is not to be shut off and become chronic.

#### **Measures Promoting Lung Expansion**

It is impossible to speak of pleural drainage without referring to the measures to be used to promote lung expansion and incidentally to prevent flattening or deformity of the chest or scoliosis. In stubborn or difficult cases lung expansion may be aided by constant negative suction (e.g. 2 to 8 cm Hg negative pressure) applied by means of a Roberts bottle or when the patient is mobile by Brock's portable suction apparatus. This suction can never make up for inadequate drainage it must never be used to suck pus out through a small hole when it should really run out through a large hole nor should it be allowed to replace proper breathing exercises to which it is merely complementary. These should be taught by a trained masseuse and the patient should be impressed with the need for daily hard work in their observance it is not enough for him to spend a gentle ten to twenty minutes with his instructor each morning but he should try to devote to them a total of several hours a day by himself. The best type of exercises are those of the inspiratory type described by McMahon which aim at restoration of proper and symmetrical costal breathing and controlled diaphragmatic movements. They are supplemented by appropriate remedial exercises to maintain proper posture. The use of the homely blow bottle is not to be recommended although it has a place in certain selected cases. The treatment of an empyema should moreover be ambulatory as soon as the patient's general condition allows him to get up. Proper



expansion of the lung and obliteration of the infected pleural dead space is thereby hastened, always provided adequate and correctly placed drainage is maintained.

As a contrast, how often do we see those unfortunates who have been ill for months, perhaps years, still in bed most of the time, with a horribly flattened, deformed, and seriously impaired chest and a continuously running small sinus that either has a minute tube or no tube at all, or, worse still has a strip of ribbon gauze tucked in it. Let us try to save out wounded fighting men and civilians from this fate—so tragic because it is avoidable, but one which has befallen many in the past.

Under proper and thoughtful guidance the healing of an infected pleural space can be achieved in a short time and with no permanent disability at all; inattention to the simple principles of drainage laid down here may result in the production of a chronic empyema which will entail perhaps a lifetime of suffering and disablement to the patient, and great economic loss not only to himself and his family but also to the nation, which may be called upon to grant him a permanent pension. In addition the services of a useful citizen or soldier may be unnecessarily lost. Not the least of the tragedy is that in most cases it could have been completely and easily avoided by taking proper care at one phase of management of the healing stage; in most this phase is that of regulation of the drainage tube, and occurs through failure to appreciate the seriousness of its casual premature removal.

Remember that the treatment of pleural suppuration does not consist in doing an operation on the patient. The operation for providing adequate drainage is only an incident in treatment, albeit an important one. Treatment is concerned with securing and maintaining full lung expansion and thereby complete healing of the infected pleura. So often the surgeon's interest (and indeed the interest of all the patient's attendants) becomes progressively less as the days pass into weeks after operation. The reverse should be the case: interest and attention should increase as the stage of healing advances, and in the final stages of obliteration the most scrupulous care is needed to manipulate the tube and arrange its removal at the correct time.



# THE PLASMA PROTEIN, ITS PHYSIOLOGY RELATIVE TO THE NORMAL AND FAILING PERIPHERAL CIRCULATION

By FRANK B MARSH, M D

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A review of the physiology of the plasma protein is justified at this time because of the significant position now attained by the transfusion of blood colloid<sup>1</sup> as a therapeutic agent<sup>2</sup>

The plasma protein consists really of at least three distinct protein substances, namely the albumin, globulin and fibrinogen fractions

The normal percentage of the total protein in the plasma varies from 6.5 to 8 gm per 100 cc of whole blood. The quantity of fibrinogen present is quite small compared to the total plasma protein, the bulk of the latter being made up of the albumin and globulin fractions which are present, under physiological conditions, in the ratio of two and a half to one<sup>3</sup>

The plasma proteins participate in several very important physiological phenomena<sup>3</sup>. The title of this paper, however, limits the scope of this presentation to the part that these proteins play in the maintenance of the normal and the production of the failing peripheral circulation

The plasma proteins are very complex substances and consist of molecules of very great size. It is held by some authorities that the several plasma proteins are more or less loosely united to form a fluid mass not greatly unlike the cytoplasm of a cell body<sup>3</sup>. Owing to the complexity of their structure, their large molecular weights and the loose combination of these plasma proteins, it is practically impossible for them to pass through a semi permeable membrane such as that constituting the capillary walls. The plasma proteins are thus very largely held within the vascular lumen and prevented from passing out into the intercellular spaces

It is of the greatest importance, in this connection, to remember that the vital functions and main purposes of the circulation are carried out in the capillary bed. The heart, arteries and veins, on the other hand, constitute merely a propelling and conducting mechanism for the circulation of the plasma and the cellular constituents of the blood. It is important to remember also, that the capillary bed is so very extensive that, should all of these little vessels be allowed to function simultaneously, the capillaries alone could accommodate the entire blood volume<sup>4</sup>

It follows therefore that in health only certain portions of this capillary system are functioning at any given time. In the ordinary



course of events a demand set up by the tissues locally determines the activity of any group of capillaries under consideration.

It is held that the accumulation of metabolites and a decreased oxygen tension, in the tissues at the site, initiate the capillary activity.<sup>4</sup> In this manner the operation of capillary circulation is regulated to meet the present need and, under normal circumstances, an adequate oxygen supply to the tissues of the body is maintained. It should be stated at this point that the capillaries have the ability to constrict or dilate in response to the demands of the tissue cells, regardless of the state of tone of the arterioles.<sup>5</sup>

In a consideration of the maintenance of an efficient capillary circulation several factors must be kept in mind. There must be (1) an effective force from behind (adequate cardiac compensation), (2) a reasonable degree of resistance in front (normal arteriolar constriction), (3) a proper distribution of electrolytes, (4) the normal concentration of plasma protein within the vascular lumen, and (5) the physiological reactivity and permeability of the capillary wall.

Assuming an adequate concentration of protein in the plasma, the normal fluid balance is determined by the proper ratio existing between the potassium within the cell body and the sodium ion in the extracellular fluid.<sup>6</sup> Inasmuch as the potassium ion within the cell is, prac-

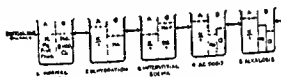


DIAGRAM I

Each of these figures represents a vessel consisting of two compartments separated by a semi-permeable membrane. In this way the relationship of the extracellular (A) and intracellular (B) fluids is diagrammatically presented.

Fig. 1. The equal concentration of the Na and K ions results in the state of normal hydration.

Fig. 2. The loss of sodium ion results in an intracellular edema and an extracellular dehydration. This may result from a localization of sodium in a pathological lesion, i.e., pneumonia or an extensive burn, or as a consequence of this unreplaced loss of the electrolyte from the body.

Fig. 3. The presence of an excess of the Na ion in the body brings about the retention of an abnormal amount of water in the extracellular spaces, instituting a state of general edema.

Fig. 4. In the development of dehydration, the loss of a relatively larger amount of the Na ion gives rise to a relatively larger quantity of the Cl ion in the extracellular fluid. The result is a state of acidosis.

Fig. 5. The loss of a relatively larger amount of the Cl ion results in the development of a state of alkalosis, being the counterpart of the condition illustrated in Figure 4.



tically speaking a fixed quantity, one may say that the proper distribution of water in the body is determined by the quantity of the sodium ion in the extracellular fluid. A surplus of sodium in the body results in the retention of an excess of fluid in the intercellular spaces while a deficit of the sodium ion in the organism is accompanied by a state of dehydration.

The electrolytes and other crystalloids are freely soluble in water and in solution are capable of readily permeating the semi permeable membranes of the body. The plasma proteins on the other hand are of such structure and character that they are practically incapable of permeating animal membranes such as those constituting the capillary wall. Because of this characteristic they are quite effectively retained within the intravascular lumen and on the basis of the principle underlying Donnan's Equilibrium and materially in the proper distribution of water and electrolytes in the body.

The ability of the protein added to a solution of electrolytes on one side of an animal membrane to attract water from the other side of that membrane and to produce a perfusion of crystalloids until an equilibrium is reached (osmosis) is the principle of physics underlying the process stated above. The power of the protein to perform this phenomenon is in direct proportion to the concentration of the protein in the solution. It follows therefore that any change in the quantity of the protein in the fluid under such circumstances will be followed by a shift of water and electrolytes until a new equilibrium is established.

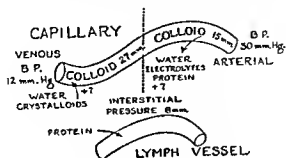
The operation of this physical law plays a very important part in the determination of the character and efficiency of the peripheral circulation. The presence of the normal concentration of the protein in the plasma not only materially influences the volume of the circulating fluid (as will be shown subsequently) but assists considerably in the interchange of water, the electrolytes and other crystalloids between the intra and extravascular spaces.<sup>6</sup> This latter process is the result of two types of physical phenomena: first a filtration of water with its dissolved substances from the arterial end of the capillary and second an osmotic pressure in the venous end of the capillary which brings about the re-entrance of an approximately equal quantity of water with its soluble substances.<sup>3</sup>

So long as (1) the capillaries possess a normal reactivity and permeability (2) the concentration of the plasma protein is within normal limits (3) the electrolyte balance is maintained and (4) cardiac compensation is intact the blood volume remains practically constant and the capillary functions are properly carried out. Diagram Two schem



*The Plasma Protein, Its Physiology Relative to Peripheral Circulation*  
 atically illustrates the operation of these physical phenomena.<sup>8</sup>

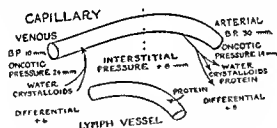
When the plasma protein concentration is decreased, however, two deviations from the normal must result. These are: (1) owing to the greater differential between the osmotic pressure and the filtration force in the arterial end of the capillary, a greater quantity of fluid is made



NORMAL FLUID BALANCE

DIAGRAM II

to filter from the vessel at that point; (2) because of the decreased concentration of the protein in the venous end of the capillary, a smaller quantity of fluid than that which escaped in the arterial side is made to re-enter the vessel at that point. These deviations from the normal result in the accumulation of an excess of fluid in the extravascular spaces. Diagram Three graphically illustrates this disturbed mechanism.



DISTURBED FLUID BALANCE

DIAGRAM III

### Traumatic Shock

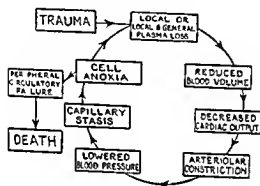
Should the decrease in the total protein of the plasma occur rapidly as a result of an increased permeability of the capillary wall to all the constituents of the plasma, the occurrence of the phenomena just described would be considerably augmented. Should such a condition arise in the course of a few hours, it would be followed by several definite and recognizable effects. First, there would occur a decreased blood



volume, second, there would result a decreased cardiac output, third, there would develop a significant degree of hemoconcentration, and fourth, as a result of the foregoing events, peripheral circulatory failure would follow, unless the disturbed physiology should be corrected.

Thus we see presented on a plausible basis the findings which characterize clinical traumatic shock. In fact, it is only upon the basis of the rapid loss of large quantities of plasma from the capillaries, the walls of which have been made definitely more permeable to the plasma protein, that all the features of this type of shock can best be explained.

Irrespective of their inclination to subscribe to the theory of the local<sup>7</sup> or the local and general<sup>4</sup> initial loss of blood volume, most authorities have agreed that the loss of the plasma components of the



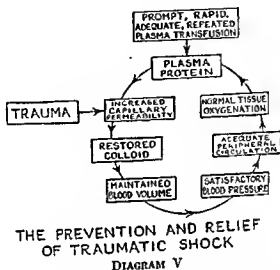
THE DEVELOPMENT OF  
SHOCK FROM TRAUMA  
DIAGRAM IV

blood constitutes the fundamental or basic factor in the production of clinical traumatic shock. The trauma alone, the toxic substance, or the combination of the two, results in the dilatation and an increased permeability of the capillary wall so that the plasma protein, along with the other plasma elements of the blood, is allowed to escape into the extravascular spaces. Thus, there is produced the decreased blood volume, the reduced cardiac output and the concentration of the cellular elements of the blood. The hemoconcentration, the increased viscosity of the blood, the decreased blood pressure and the circulatory stasis as it occurs in the dilated capillaries result in cell anoxia. It has been proven that tissue anoxia itself is capable of and does initiate the dilatation and an increased permeability of the capillaries. Thus there is produced the greater dilatation of the capillaries and a more widespread and profuse loss of the intravascular fluid resulting in the further decrease in

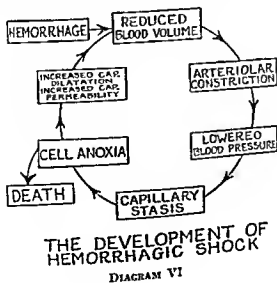


# *The Plasma Protein, Its Physiology Relative to Peripheral Circulation*

the blood volume and more marked hemoconcentration.<sup>4</sup> In this way a vicious circle is instituted with the establishment of irreversible shock. Eventually the peripheral arteriolar constriction fails to compensate for the increasing loss of blood volume, the vital centers suffer from anoxemia, the peripheral circulation ultimately fails completely and death supervenes.



This pathological trend toward a failing peripheral circulation may be satisfactorily corrected and recovery induced if the impending failure is anticipated or recognized and the proper therapy instituted, before the irreversible phase of the shock has developed.

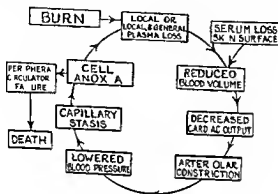




This method of treating severe hemorrhage will often prove life saving in the smaller hospitals where a large blood bank can not be maintained

### The Shock of Burns

The character of the shock associated with burns is identical in all respects with the usual features of clinical traumatic shock<sup>8</sup> The decreased blood volume the diminished cardiac output the hemoconcentration and the subsequent peripheral circulatory failure all manifest



THE DEVELOPMENT OF THE SHOCK OF BURNS

DIAGRAM VIII

themselves in the manner previously described. There is in addition to the underlying pathology however a considerable loss of the plasma protein into the burned areas and as an exudate into the large bullae and from the raw surfaces produced as those lesions become ruptured. The quantity of this fluid which is lost from the general circulation in this manner in the more extensive second degree burns is often quite great. This loss of serum protein added to the plasma protein escaping into the extravascular spaces as a result of the shock factors facilitates considerably the production of the diminished blood volume. It is quite often the case that this additional loss of plasma protein hastens the development of shock is the deciding factor in the development of the irreversible phase of the shock and frequently tips the balance between the life and death of the patient.

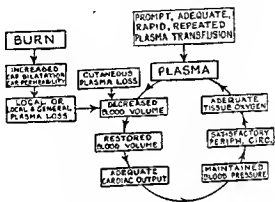
Here again the maintenance or the re establishment and maintenance of an adequate blood volume is from the standpoint of the disturbed physiology the indication to be met. The loss of blood colloid into the burned areas and from the skin surface added to that dissipated from the capillaries as a result of the shock factors makes the reintroduction



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into the circulation of adequate blood colloid pre-eminentlly urgent and imperative. As in traumatic shock, the restoration of the plasma protein reverses the pathological shift of fluid and electrolytes, re-establishes the blood volume, relieves the excessive arteriolar constriction, alleviates the hemoconcentration, and prevents the capillary stasis and tissue anoxia. Thus the peripheral circulation is kept intact and the clinical manifestations of shock are prevented.

Most important, however, the development of shock accompanying burns must be anticipated. The colloid must be administered promptly



THE PREVENTION AND RELIEF  
OF THE SHOCK OF BURNS  
DIAGRAM IX

before serious indications arise; the quantity of plasma or serum must be adequate; and, finally, the transfusion must be repeated often enough to meet the need of the particular patient being treated. In no other way is it possible to restore and maintain the normal physiological processes of the body and safeguard the life of the burned individual.

### **Hypoproteinemia**

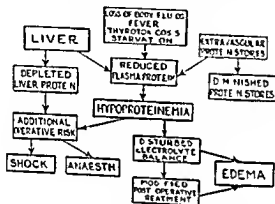
The effect which hypoproteinemia produces on the competency of the circulation has already been described. The decreased concentration of the plasma protein (1) allows the filtration of a greater quantity of intravascular fluid into the interspaces, and (2) fails to effect the re-entry of an equal quantity of fluid into the venous end of the capillary. Thus there is brought about the accumulation of an excess of the extravascular fluid. Therewith occurs a shift of electrolytes and some degree of interference with the peripheral circulation and tissue oxygenation.

After the amount of the extravascular fluid increases sufficiently the presence of clinical edema can be detected. While it is true that a large amount of interstitial edema may occur before its presence can be de-



terminated the important point is that, long before the hypoproteinemia manifests its presence, the body reserves of protein (extravascular fluid protein and hepatic stores) have been considerably exhausted

As a result of hypoproteinemia traumatic and surgical shock occur on less provocation than when this pathological condition does not exist. Because of the lowered concentration of plasma protein there is greater susceptibility to the toxic effects of chloroform<sup>9</sup> <sup>10</sup> and no doubt, other anaesthetics and certain drugs (arsphenamine<sup>11</sup> sulfonamide preparations cinchophen etc.) When the hypoproteinemic state exists much



HYPOPROTEINEMIA  
DIAGRAM X

greater care must be exercised in the administration of parenteral fluids following operations<sup>12</sup>. It is obvious that with the administration of considerably less normal saline solution the patient may have excessive water retention, diminished circulatory efficiency and such embarrassment to his vital functions that he succumbs because of these additional burdens.

It is sufficient to say that in practically all instances of hypoproteinemia the re-establishment of the normal concentration of protein in the plasma will be accompanied by a correction of the disturbed physiology mentioned above. The excessive extravascular fluid will be attracted into the capillaries, a redistribution of the electrolytes will occur, the excessive quantity of water will be eliminated by way of the kidneys and the proper fluid balance and normal blood volume will be re-established. In this manner the peripheral circulatory embarrassment will be overcome.

So long as the gastro intestinal functions are intact an adequate intake of protein foods by mouth is sufficient to meet the physiological requirements. In post operative conditions or in long illnesses during



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which a sufficient intake of protein is not possible, the indications are not so easily met. In these instances the parenteral administration of human plasma, serum, or whole blood is necessary to maintain a normal fluid balance and insure an efficient peripheral circulation. Such transfusions must be given as frequently as the indications for them may arise

### Conclusion

The extremely important part that the plasma protein plays in the operation of the physiological processes of the body must be appreciated and understood in order to employ most intelligently and effectively the transfusion of blood colloid in the treatment of disordered states.

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# DETERMINING FACTORS IN THE END-RESULTS FOLLOWING WAR WOUNDS AND COMPOUND FRACTURES

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There was a short period in the history of surgery when we could be and were quite definite about our attitude toward compound fractures and compound fracture wounds. We did not treat the wound. The wound dressing was designed only to exclude infection. Unfortunately, this period was very short. I refer to the time about 1865 to 1870 when the true Lister method was proposed, described and employed by Joseph Lister himself.

In discussing wounds and compound fractures I shall first remind the reader that in order to deal successfully with this problem we must return not to the technique or to the exact method of Lister, but to the Lister point of view. This original conception was described perfectly by Lister and was really comprehended by many of his pupils and contemporaries. Even a few of his successors were able to maintain the original Lister attitude toward wound infection. Generally speaking those surgeons who adhered to the Lister ideal were few, while those who departed on various paths and in many directions were many.

As an illustration I may quote from Dr James L Little (in 1877) lecturer on operative surgery and surgical dressings in the College of Physicians and Surgeons New York:

We will turn our attention this morning to the subject of antiseptic surgery, a topic at present of universal interest and one with which even should you never practice it, scientific medicine demands that you should be familiar. Professor Lister, accepting the germ theory, has applied to the treatment of open wounds an entirely new method which has so far yielded the most wonderful results. The principle of Lister's method is essentially this: In treating an open wound let neither the air, the instruments you use, your hands, or the dressings that are to be applied, nor in fact anything come in contact with the wound unless it has been thoroughly saturated or wet with a solution of carbolic acid, and at the same time keep the wound thoroughly drained.

This was *not the principle* of the Lister method, only some of the details of the Lister technique from which Dr Little and many others promptly departed.

Dr Little continued: Carbolic acid comes in crystals, but the addition of a little water dissolves them. You should procure two bottles, one that will hold a quart and one that will hold two quarts, and



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two-ounce graduate. To 30 ounces of water add an ounce and a half of the carbolic acid and you have a solution of the strength of one part of carbolic to twenty of water. From the two quart bottle pour off four ounces and add the same amount of carbolic acid. You then have a solution of one part of carbolic acid to forty of water. Now you are ready to employ the Lister method so far as the solutions are concerned."(!)

Dr. Little described at the same time, the use of thymol which had been employed not very successfully by Dr. Weir. Dr. Little expressed the hope, however: "That some more pleasant antiseptic will soon be discovered to take the place of the disagreeable carbolic acid."

Dr. Little employed the spray and described its use in great detail. Then he said: "We will now turn our attention to the antiseptic gauze. This is made of very coarse muslin or cotton gauze sprinkled with a hot mixture of resin and paraffin and one part of crystallized carbolic acid. Another material which can be prepared in the same way or purchased from a dealer, is the mackintosh cloth or protective oiled silk."

Lister taught that a certain kind of safety pin should be employed with a guard protecting the point of the pin. He said that even a pin hole through the mackintosh might permit the entrance to the wound of enough germs to cause the death of the patient.

In 1877, however, both Lister and Dr. Little were advocating the use of rubber drainage tubes. These tubes damaged the wound surface and permitted the access of new infection to the deep recesses of the wound.

These inconsistencies—exposure for dressings with damage to the wound surface, and the drainage tube opportunity for infection, have led to many of our difficulties in the control of fractures and in the protection of the wound against secondary infection. They have led to pyemic and septicemic complications and have predisposed to inflammation, scar formation, disability and deformity.

In 1904 when I began the study of orthopedic surgery I was drilled by Dr. Ridlon in the teachings of Hugh Owen Thomas (even with regard to intestinal obstruction) but he never did ask me to read the writings of Lister. I had not read all of them until after the war of 1917-1918. It had been my impression that Lister's original writings were very much out of date. I was familiar with the fact that Lister had renounced the antiseptic method as far as the carbolic spray was concerned. I thought then, as I have found many other surgeons to think, that Lister had abandoned his original conception of antiseptis when he abandoned the spray.



As I re read the writings of Lister in 1919, I found that he had, to an extent, receded from his original teaching as to the exclusion of infection. He did allow himself to be influenced by his colleagues and his contemporaries to begin the search for a less offensive chemical than carbolic acid and for one which might actually cure wound infection.

But while Lister had been led by Robert Koch and others to try mercurial antiseptics, he regretted a tendency toward careless chemical dressings as a substitute for exclusion. Chemical wound dressings and chemotherapy were not then and have never been the true Lister method.

It is this search for a chemical that will kill germs without harm to the patient that has done antiseptic and aseptic surgery much harm. For example, a British surgeon said in 1918: "In dealing with compound fractures and compound fracture wounds it is important for the surgeon not only to defend against infection, but to know when to attack." But what many of us forgot in those days was that in attacking the infection we were often attacking the patient as well, and about the time that the infection and the germs were in retreat, the patient was about ready to surrender also.



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peutic technique and apparatus for different patients, different occasions and especially for different splints and surgeons to arrive at standard methods, continuity, or systematic treatment.

A common admonition of surgeon-teachers is that the surgeon on the spot in an emergency must decide the special apparatus, methods, and program appropriate for any patient. Every surgeon should have in mind that certain fundamentals, such as, restoration to normal position, immobilization, control of hemorrhage, and protection against further trauma and infection are essential and should always come first.

In acute infections even more than in chronic bone and joint disease, immobilization and rest are necessary to avoid or reduce inflammation, scarring and subsequent fixation, adhesions and ankylosis.

We do not seem to have arrived at this "rest" point of view for the acutely inflamed fractures and compound fracture wounds. There is still the attempt to diminish the amount of apparatus, to provide more joints and mobility, to make our patients ambulatory and to render less efficient rather than more so the kind of control which Thomas described long ago as rest "enforced, uninterrupted and prolonged."

We should not forget that scarring, stiffness and disability in the vicinity of fractures are brought about by improper motion, inflammation and irritation just as they are in tuberculous joint disease.

When I began my infrequent-dressing and rest method for osteomyelitis, infected wounds and compound fractures about twenty years ago, I had become convinced that the Carrel-Dakin, Willems, and Blake teachings, and primary and secondary suture were all doing much harm. My feeling arose partly out of realization that the teachings of Lister, Hilton, Hugh Owen Thomas and Ridlon regarding infection and rest were being violated. I believed firmly *that wound surfaces should be protected, that infected wounds of any degree should be drained, that all fractures should be reduced and immobilized, and that any injured or inflamed limbs should be protected against muscle spasm and other painful movements.*

A very few clinical trials were sufficient to convince me of the correctness of these assumptions. Many years of further clinical experience have assured me that these fundamentals are correct but that other details of treatment are often incidental and unnecessary.

*My own results have been obtained without sutures, without drainage tubes and without antiseptic wound dressings. Sometimes cures or results attributed to chemical agents or "modified" techniques have been attributed wrongly to them, when better immobilization, rest and protective methods have given the patient his own chance to recover.*



I could quote many reports from recent literature to illustrate this point. Perhaps one from a New York surgeon will be sufficient. In Bone and Joint Surgery for October 1941 he says: "I have recently treated 45 fractures of the tibia by open operation. The results in all 45 cases have been good though recovery in one or two was somewhat delayed. To date there has been no loss of life or limb attributable to the open method despite the fact that as yet none of the newer drugs such as sulfanilamide has been used as a prophylactic against infection. I am not quite sure whether this New York surgeon is being naive—a term sometimes reserved for those of us from the provinces—or whether he is pulling our leg."

In this connection we might do well to recall what Dr. Flexner said in his book on Medical Education. There is a wide spread impression that the scientific quality of medical practice is dependent upon the part played by the laboratory. This is not the case. Clinicians especially are inclined to regard the laboratory worker as always scientific and more or less infallible. It should be remembered I think that mistakes as to cause and effect so often attributed to the clinician may be made by the laboratory worker too especially if he tries to carry his methods and conclusions into the field of practice.

It is interesting that in recent months a piece of research has been carried out which has had the effect of rationalizing completely all of our contentions regarding the importance of immobilization and rest in the treatment of inflammation and infection. This work was done in part by Dr. Trueta who made such a fine contribution to the plaster of Paris cast and infrequent dressing method by his work in Barcelona during the Spanish War. Dr. Trueta has recently been at Oxford, England and has conducted a study with Dr. Barnes of Oxford on the influence of immobilization upon the lymphatic circulation in the extremities. Barnes and Trueta published in the *Lancet* London May 17 1941 page 263 an article on the absorption of various toxins and other materials from the mesenchymal tissues under circumstances similar to those in wounds and compound fractures.

Barnes and Trueta tied off the lymphatic circulation in animal limbs and introduced certain organisms into the tissues. They found that with the lymphatics obstructed very few of these organisms got into the blood or into the spleen. Also even from recent wounds very few organisms were taken up by the freshly injured blood vessels but such as were carried into the body of the animal at all were taken by way of the lymphatics.

Snake venoms some of which were so poisonous that they would



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kill animals in ordinary ways within ten minutes, could be excluded from the body of the animal generally by obstruction of the lymphatic circulation in the poisoned extremity. As soon as the ligated lymphatics were relieved, however, even after an hour or so, the poison which had been held in the extremity by this ligature, escaped into the body and the animals promptly died.

Another experiment had to do with the reduction of the lymph flow by physiologic means. Rabbits had their lower extremities completely immobilized by means of plaster-of-paris double spica casts. Then snake venom was injected into the immobilized lower extremity, and one animal was found to be perfectly well after 105 minutes; then the plaster was removed and the animal allowed to move the limb about and died within seven minutes. A second animal remained in plaster for 210 minutes and died 60 minutes after the removal of the cast.

One method by which edema may be prevented, Dr. Trueta says, is by the enclosure of the injured parts in a plaster cast. The reduction of the lymph flow obtained by this means is further enhanced *if local drainage of the inflamed parts is provided by incision.*

The support adduced, by Dr. Trueta's research, for the immobilization and skeletal fixation of these extremities in plaster-of-paris is of the greatest importance. It has an important bearing on the immobilization and rest treatment of all infected wounds and fractures. It not only explains the excellent results we have obtained by this method, but points the way to further study along this line.

I wish to refer briefly to the report of the Committee on Fractures and other Traumas published in *Surgery, Gynecology and Obstetrics*, November, 1941. This resolution was adopted at New Orleans last January. The conclusions of this Committee may be summarized as follows:

1. The use of snug-fitting plaster encasements in initial treatment of acute compound fractures is inadvisable.
2. Early splinting, utilizing fixed traction, should be followed by adequate debridement at the earliest possible time.
3. Wounds of the soft parts, not involving bones, joints, nerves or tendons, may be closed by secondary suture when bacterial checks in the laboratory prove that closure of the wounds is permissible.

My answer to these three proposals in general is that they represent the point of view that prevailed during the War of 1914-1918. That our results then were most unsatisfactory no one now attempts to deny.

With regard to the use of plaster, thousands of surgeons are now prepared to assert that properly applied plaster-of-paris casts may and should be used immediately after compound fractures. If such fractures



are reduced if the limb is put in the cast in correct length and position and if the wound is protected against secondary infection, this represents\* to many of us ideal treatment (which permits transportation) under any circumstances

With regard to temporary splints and secondary debridement this involves secondary trauma to the wound disturbance of the limb and the patient and revision of the fracture. Many of us feel that such treatment is quite wrong. Primary reduction direct or indirect fixation in plaster of paris casts and with no change for several weeks is much to be preferred. This method is in extensive use here and in war areas abroad

With regard to the closure of wounds there are practically no such wounds such as those described by the Committee as suitable for primary or secondary closure. We are not much concerned about abrasions and skin wounds but for those which do involve tendons joints and bones more important surgery operative and postoperative primary and secondary is required

The outline of treatment proposed in the Committee's report is an outline which was carefully considered thoroughly tried and largely discarded after our military experience twenty years ago

One of the common misconceptions with regard to the infrequent dressing method is that the patient is likely to become septicemic pyemic or toxic as a result of foul smelling dressings or casts. That a bad odor is a necessary concomitant of this method is an entirely erroneous idea. Such wounds and discharge as do have bad odors have them because of contamination with certain saprophytes that occurs at the time of injury at the time of operation or quite often because of careless secondary dressings. In most of our cases whether of wounds or compound fractures no postoperative odor is associated with the case at all. The patients we receive late after they have been contaminated already are sometimes difficult to clean up and for a time may have disagreeable odors. Even such cases however can usually be kept clean and dry so that the odor disappears. Then they make a satisfactory convalescence without further difficulty from odor or otherwise

Another misunderstanding as to skeletal fixation is that the primary reduction and fixation of the limb must undergo revision and readjustment if it is found that the fracture surfaces are not perfectly approximated. Spaces between the ends of the fractured bones will fill in with callus and bone repair if they are truly immobilized in correct position and are undisturbed during convalescence. No delay in union is to be anticipated even if the fragments are slightly separated<sup>2</sup>



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A diversion that is a common cause of inefficiency in fracture treatment arises out of the idea that the patient will be better off if he is made ambulatory. There is seldom any justification for trying to get a leg or femur fracture patient on his feet. As for moving joints in the vicinity of fractures, this is still as wrong as it was before skeletal fixation was invented. Certain complications, such as localized infection, failure of union and even stiffness of joints are much more likely to occur in any ambulatory fracture patient.

A final point that I should like to emphasize is that it is seldom necessary to experiment upon the patient with new methods or techniques. It is quite possible to decide upon theoretical grounds whether a new treatment is likely to do more harm than good. If a proposed treatment is inefficient for fracture reduction, if it fails to provide or prevents adequate drainage of an infected wound, if there will be motion or muscle spasm or pain in a fracture area, if the fracture must be readjusted after reduction, or if the wound must be traumatized or exposed to reinfection, the new method is probably not worth a trial. It will usually be better to adhere to the methods we now have and that do not neglect or violate the fundamentals of reduction, asepsis, drainage, immobilization and rest.

It is always the duty of the surgeon, not only to provide proper conditions for recovery, but to protect the patient, as far as possible, against his own voluntary, or involuntary, violations of the treatment regime, or other indiscretions.

<sup>1</sup> From a *Series of Clinical Lectures*, Edited by E. C. Seguin, Vol. III, No. xl, p. 298. New York, G. P. Putnam & Sons, 1876.

<sup>2</sup> The contention that the ends of the fragments separate because of absorption and must be brought together by secondary adjustment is also wrong. If the fragments are in correct position and truly immobilized from the beginning, absorption at the ends will not occur.



# FRACTURES SUSTAINED IN WAR

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The treatment of simple fractures under war conditions differs in no way from their treatment in ordinary life. First aid protection, early reduction and proper immobilization are the main indications.

According to the statistics of the last war as published by Love, the casualties of the U S Army showed that 54 per cent were soft part wounds of the extremities, 29 per cent were compound fractures of the extremities, 9 per cent involved head and spine, with involvement of chest and abdomen 1 per cent each. The compound fractures, therefore, are a most important group.

The pathological status of these compound fractures produced in war differs from that encountered in civilian life in several ways. There is much greater comminution. Instead of two or three fragments, an area of 5 to 15 cm of bone will be completely shattered with a corresponding amount of soft part damage. With rifle or machine gun wounds the soft part damage and contamination may be minimal but in cases produced by shell and bomb fragments the damage is often extreme. The large, lacerated wounds contain bits of clothing and other foreign bodies. Another difference between the civilian and war problems is that of transportation which has an important bearing on treatment. In civilian work the first trip the patient has may be long and difficult but once he arrives at a hospital he can receive his surgical treatment and then be kept quiet as long as may be necessary. Under war conditions treatment is often interrupted by several moves in the first few days and the treatment must be planned to meet this difficulty.

Even with these differences in the pathological condition, the fundamental principles of treatment of compound fractures sustained in war are the same as those encountered in civil practice. These principles are based on the facts that we are dealing with individuals who have received injuries to their bones and soft parts, with open wounds communicating with these injured areas and with contaminating material introduced into the depths of the wound. The Army Medical Corps can do nothing to control the extent of the original injury but it can do a great deal to reduce the amount of secondary trauma the wounded man is exposed to after he has been hit. The object of the first aid treatment is to reduce this secondary trauma to a minimum. This involves protection of the wounds early splinting and the use of chemotherapy at the earliest possible moment. The British Army in the last war reduced



their mortality in compound fractures of the femur, from 50 to 15 per cent by the application of Thomas splints by the stretcher bearers. The reports from Pearl Harbor of the delay in the spread of infection by the early use of the sulfa drugs are most encouraging. The results of tetanus toxoid immunization promises even to surpass the efficacy of the use of antitoxin.

The second principle is the operative treatment of the wound at the earliest possible moment. In addition to the broken bone there is lacerated muscle and fascia, much of it damaged beyond repair. This dead and dying tissue furnishes ideal conditions for the growth and activity of the contaminating pathogenic organisms introduced into the wound. These must be removed by careful dissection and irrigation. Surgical cleansing of the wound, called debridement, needs extreme care and gentleness in order to lessen the secondary trauma and to avoid spreading the contamination to the deeper planes. Under complete anesthesia and with traction maintained, the wound is protected by gauze while the surrounding skin is thoroughly but gently scrubbed with soap and water. The injured part is then draped and the excision of traumatized tissue and foreign bodies carried out with sharp dissection. This is done in layers with frequent change of instruments. At the same time the wound is irrigated with plentiful amounts of saline solution. Four quarts is a minimum amount. In irrigating the deeper planes, the sides of the wound are retracted and the nozzle introduced so that the flow will be from within outward. The object is to wash *out* the wound not to wash *in* contaminating material. The debrided tissue should be put into a sterile container for aerobic and anaerobic cultures to establish the character of the contaminating organism. On completion of the debridement, salt solution from the depths of the wound should be cultured to test the efficacy of the operation. The result of these cultures will be of help in deciding on the future treatment of the wound.

The next problem is to bring the bone fragments into normal alignment and to apply dressings to the wound. At this stage, one of the protective drugs is introduced into all the planes and crevices of the wound and the surfaces separated by vaseline gauze. Although some surgeons are of the opinion that these wounds can be closed if seen early and properly debrided, I believe strongly that they should be left open. Many successful primary closures are reported but when they are not successful the results are often calamitous. Tension within the wound favors bacterial growth. Which of the various sulfa drugs or zinc peroxide is the most efficacious for local use in these wounds is still a debatable point to be established by further experience. Apparently,



if one of the sulfa drugs can be introduced into the wound as a primary dressing procedure and the oral administration started at the same time, the surgical treatment can be carried out with success at a much later period than if the drug is not used. Six to eight hours was formerly thought to be the safe period without the use of those drugs. With their use such treatment may be successful after even two or three days.

The next step in treatment is the immobilization of the injured part. This can be accomplished by traction and suspension, by circular plaster splints alone, by wire or pin traction, the wires or pins being incorporated into plaster or into some external appliance such as the Roger Anderson method or by rigid internal fixation by plates and screws. These various methods have been enumerated in the reverse order of their efficiency. Suffice it to say that the constantly repeated movement of the bone fragments during transportation and dressings is a large factor in the spread and continuation of infection.

### Summary

Compound fractures form a large percentage of war wounds. Although the pathological status is more complicated in war wounds, the principles of treatment are the same: (1) first aid protection of wounds, early splinting, early use of drugs, (2) operative cleansing of the wound at the earliest possible moment, (3) reduction of fragments and (4) immobilization.



## MARCH FRACTURE

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The term "march fracture" is applied to fracture of a metatarsal occurring in persons who have experienced prolonged and repeated foot strain, but who have not suffered a single obviously severe injury. This syndrome was brought into prominence during the first World War, although it has been described as early as 1855 by Breithaupt, a Prussian military surgeon, who named it "Fussgeschwulst." Stechow (1897) is credited with first making the diagnosis by means of the roentgenogram, and demonstrating the presence of a fracture. Since then the subject has been thoroughly discussed in the European literature. Maseritz<sup>2</sup> has compiled an excellent bibliography of these writings.

A few papers have appeared in the American literature in the last decade, notably by Speed and Blake,<sup>4</sup> Meyerding and Pollock,<sup>3</sup> and Zeitlin and Odessky.<sup>5</sup> In spite of this, the post-war generation of physicians is still prone to overlook this disability, as is evidenced by the fact that we have recently seen a number of cases in which the correct diagnosis was not suspected until roentgenograms were made.

Hundreds of thousands of young men are now entering the Army. In the course of their military service these men will walk distances much greater than they were accustomed to walking in civil life, and as a result, this otherwise infrequent clinical entity is certain to increase. The author saw only one case in three and a half years prior to entering on active duty with the Army, but has seen 9 cases in six months at the Station Hospital, Fort Jackson, S. C. A search of the files revealed one additional case.

We wish, therefore, again to call attention to this syndrome, to review the clinical findings and symptoms of "march foot," and to demonstrate the various roentgenographic appearances.

### Etiology

The pathogenesis of these fractures is not clearly understood. This fact is best demonstrated by the multiplicity of theories advanced by different authors. Periostitis, myositis, disturbed circulation, pes planus, a short first metatarsal, bacterial or trophoneuritic factors have been variously suggested as the underlying or predisposing causes. We do not propose to discuss these hypotheses, but point out that all patients give a history of prolonged and repeated foot strain, such as would be sustained by marching, hiking, or standing for long periods of time.



Brandt<sup>1</sup> has ably summarized this by stating that these fractures are the result of rhythmically repeated, subthreshold mechanical insults, acting by summation, to a point beyond the capacity of the bone to bear stress (The ability to bear stress may be reduced by the other factors mentioned above)

This overload of the functional capacity of the bone is the direct cause of the fracture, whatever the predisposing conditions may be. Therefore, any person whose feet have been subjected to such conditions, in military or civil life, should be suspected of having a "march foot"

### **Clinical Findings**

The onset may be abrupt or insidious. Although in some cases the patient insists that the first pain experienced was severe and sharp, the onset in the majority of cases is gradual. The first symptom is usually a slight discomfort in the metatarsal area, which slowly increases in severity and is manifest only when the body weight is placed on the foot. The patient walks with a limp to lessen the weight borne by the metatarsals. Relief is obtained by rest and elevation of the foot.

This pain and its accompanying tenderness are usually localized to the site of the fracture. Motion at the ankle joint or the toe is not painful. A definite edema of the dorsum of the foot soon appears but will disappear with rest. Later this is replaced by a smaller, localized, harder swelling, i.e., the callus. Crepitus is not felt.

### **Roentgen Examination**

Technically perfect roentgenograms, showing maximum detail, are needed to make the diagnosis early in the course of this ailment. This point cannot be emphasized too strongly. For this reason cardboard film holders should be used, preferably with non screen film, and the smallest focal spot available should be employed. The target film distance should be at least 36 inches to minimize distortion, and the foot must be firmly immobilized during the exposure. At least two views, the postero anterior and the oblique, should be taken.

On the basis of the changes seen on the roentgenograms, we may divide this syndrome into four stages. It is most important to remember that a roentgenogram taken during the first stage (within the first seven to ten days after the onset of symptoms) may show no pathologic changes. Because the fracture line is narrow and often incomplete, and because no displacement occurs, it is difficult to demonstrate the fracture. Even on technically perfect roentgenograms the fracture line may not be visible, but the better the quality of the roentgenogram, the better the



### *March Fracture*

chance of demonstrating the fracture. If the fracture line is demonstrated, the diagnosis is obvious.

In the second stage, from one to three weeks after the onset of symptoms, a loosely calcified and fuzzy callus is seen in the shape of a spindle or cylinder around the shaft of the second or third metatarsal. Any other location is very rare. At this time the fracture line is visible in most cases. If the foot has not been placed at rest immediately after the onset of symptoms, the loose callus is surprisingly abundant.

In the third stage, after immobilization in a plaster cast, the callus becomes denser, more circumscribed, more sharply defined, less bulky and looks "harder." This takes another three to six weeks. The fracture line is often still visible.

In the fourth and final stage, several months later, the only remaining sign is a slight thickening of the cortex.

Roentgenographically considered, march fracture must be differentiated from osteogenic sarcoma and Ewing's tumor. The differentiation may be quite difficult, especially if the patient is seen in the second stage, with a spindle of callus around the metatarsal. In such cases recourse to the history must be had, and careful inspection of the roentgenogram for a narrow fracture line should be made. If it is still impossible to separate these entities, a cast should be applied for three weeks, then removed and the patient re-examined. If one is dealing with a march fracture, the callus should be smaller, denser, and more circumscribed, whereas in the case of a neoplasm the spindle would be of the same or larger size. It should further be remembered that the foot is not a common site for osteogenic sarcoma or Ewing's tumor.

### **Treatment**

The treatment is that of any fracture in this area; namely immobilization, preferably in a plaster cast, for three to six weeks, followed by physiotherapy.

### **Case Report**

Complete case histories could be taken in 9 of the 10 cases seen in the Station Hospital. Two men had been soldiers for over eighteen months. Two had been laborers and 6 had had sedentary jobs before induction. All of the men were very well nourished. They ranged from slender to very heavy in build. Excluding the 2 Regular Army soldiers, the length of service before the onset of the symptoms varied from three to nine months. These men, therefore, had already completed the preliminary course of training and were in good physical condition.





FIGS 1-4 March Fracture



## March Fracture

FIG. 1. Nineteen days after onset. A faint, lightly calcified callus is seen around the distal end of the third metatarsal. A narrow, incomplete fracture line is present near the distal end of the callus. This is the second stage.

FIG. 2. Twenty-nine days after onset. The callus has increased in amount but is still fuzzy. The fracture line is barely visible. A cast was applied immediately after this roentgenogram was made.

FIG. 3. Two months after onset, and immediately after the cast was removed. The callus is smaller, denser, and "harder." It is now sharply outlined. The fracture line is not visible. This is the third stage.

FIG. 4. Three months after onset. The excess callus has disappeared. The only remaining finding is a thickening of the cortex. This is the fourth stage.

Of the 10 cases seen at the Station Hospital, only 2 were correctly diagnosed before the roentgenograms were made, in spite of the fact that the history of the present illness was clear cut in every instance. The following case history is presented as a typical example of this syndrome.

M. P., a 27-year-old laborer, entered the Army as a selectee on Jan. 10, 1941. He was assigned to an infantry regiment and given the usual course of training. He had no trouble until June 22, 1941, when, about half way through a 27-mile march, he began to notice pain on the plantar surface of the right foot. This pain gradually became more severe but was present only when the right foot carried the body weight. After a rest he was able to complete the march but experienced considerable pain. Rest and soaking in hot magnesium sulphate solution gave some relief. In the ensuing days, pain was present on walking, but since there were no further long marches, the man continued on duty. On July 10, however, he reported to the dispensary. On July 11, nineteen days after the onset, a roentgenogram (Fig. 1) showed fuzzy, loose callus formation and a narrow, incomplete fracture line in the distal portion of the third metatarsal. The patient was relieved from duty and allowed to rest the foot. On July 21, another examination (Fig. 2) revealed the callus formation to be considerably increased in amount, and the fracture line to be barely visible. At this time the patient was admitted to the Station Hospital and a plaster cast was applied. Following removal of the cast, on Aug. 18, the callus was seen to be less bulky, more dense, and sharply circumscribed (Fig. 3). The fracture line was no longer visible. There was now no pain, and the patient was returned to duty. A follow-up roentgenogram (Fig. 4) on Sept. 19, showed only thickening of the cortex. The patient was symptom-free, and has since had no recurrence of pain.

### Summary and Conclusions

Attention is drawn to the syndrome of "march foot." This entity will undoubtedly be seen more frequently as the military forces are expanded. Ten cases have been seen by the author. One typical case history is presented.

The important diagnostic points are: absence of a history of direct trauma; pain on the plantar surfaces of the metatarsals with each step; localized tenderness over the second or third metatarsal; edema of the dorsum of the foot. The onset may be sudden or gradual.

This syndrome known as "march foot" or "march fracture" may be



divided into four stages on the basis of the roentgenographic findings. During the first ten days following the onset of symptoms, an incomplete, narrow fracture line may be present, but failure to demonstrate such a fracture line does not exclude a "march fracture." In the second stage, from one to three weeks after onset, a spindle-shaped callus is seen around the second or third metatarsal and the fracture line is often visible. The amount of callus is usually large in proportion to the extent of the injury. In the third stage, after immobilization, the callus is smaller, denser, more sharply circumscribed, and the fracture line may still be visible. In the fourth stage, the only finding is a slightly thickened cortex. A higher percentage of these fractures can be diagnosed in the first stage if technically perfect roentgenograms can be obtained.

The treatment is the same as for any fracture in this region

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## AVIATION MEDICINE IN THE NAVY

By REAR ADMIRAL ROSS T. MCINTIRE  
*Surgeon General of the Navy*

There is nothing mysterious about the field of aviation. When a young man graduates from his training school and becomes a full-fledged pilot he is still the same human being that he was before he started his course. True, he is now living in a much more hazardous field of activity and will be subjected to more severe strain, mentally and physically, than he has previously been accustomed to. The old myth that people in aviation are different and set apart from their fellows is steadily being exploded. The primary duty of the doctor who is a specialist in aviation medicine is to see to it that this is true. The aviator must be made to feel that he can live a reasonably normal life and that the hazards and strain he meets in his daily duty are reasonably normal for him. If he is mentally and physically alert the hazards are not insurmountable.

For many years aviation medicine in the United States Navy was given over to an attempt to aid in the proper selection of officers and men for the various branches in aeronautics. The medical officer did his best to understand the problems that faced the aviator and attempted to help him by the different crises that came into his life. These are manifold and come from various conditions that meet the pilot in the daily performance of his duty.

The early attrition, due to crashes and neuroses among students and pilots, was very alarming following the World War, and we find exactly the same situation existing today among the pilots of the British Air Force. We are finding a like situation in our naval air force following extensive activity over a period of several months. The effect of all this is as serious as if these men had been in actual combat. Pilot fatigue and staleness are two of the most important factors that the flight surgeon has to evaluate. The good judgment of the doctor is as important as the ability to recognize the condition.

In the old days inadequate provision for artificial oxygen supply was always present. Cockpits of planes were exposed and the pilots were subjected to the bad effects of extreme cold. There was no adequate safeguard against carbon monoxide concentration from the motor exhaust. All of these things helped to add a considerable confusion that was present and had a great deal to do with the feeling that the pilot had to live a different sort of life so that he would be able to throw off the effects caused by these conditions.



Very little was done to solve the cause of fatal crashes and only haphazard research attempted in the field of atmospheric hygiene, a term which you might say was practically unknown a few years ago. True, we did try to find out something about the use of oxygen in higher levels, and the attempts to break altitude records by some of our very excellent pilots such as Champion, Soucek and others, did stimulate work in this field. The Army carried on a similar piece of work, in fact considerably more comprehensive than that done in our Service. Still, we learned very little. Spasmodic studies were carried out in depth perception, reaction time, and the proper part peripheral vision played in the pilot's ability to see moving objects at great distances, but here again there was very little continuity.

Rather serious attempts were made to find a proper means of eliminating the unfit from the psychologic standpoint. We know now that our attempts were ponderous and that hours and hours were wasted in our psychologic and psychiatric examinations.

While this work was being carried on, the mechanical side of aviation was going forward steadily. While personnel seemed to stay at a level as far as crashes were concerned, the mechanical perfection of the airplanes advanced with amazing rapidity. The World War should have taught us a great deal of the absolute necessity of being able to fly safely in altitudes well above 30 000 feet. We know that up to this time the Germans have been able to fly at constantly higher levels than their opponents. It goes without saying that the pilot who is able to come in above, and behind his opponent, has a tremendous advantage in aerial combat.

Through many years preceding the present war in Europe, Germany, and to some extent Italy, carried out very extensive research in the various problems having to do with atmospheric conditions and fatigue in pilots. Great Britain and the United States did practically nothing in this regard when compared with what was done by the countries just mentioned. In the countries of Europe it has been the custom, for many years, to test all pilots in low compression chambers so that the ceiling of the individual could be established. This was done by putting the individual through many tests, not just one. Of course, this took a great deal of equipment. Until a short time ago neither Service had an installation that contained a low pressure chamber. The only work that we could do in that regard was at the Experimental Diving Unit at the Navy Yard in Washington, where the splendid work under high pressures has been carried out by that Unit.

I have painted a very gloomy picture up to this point and it is one



that we are not proud of, but like so many things through the years there was not considered a great need for hurry in solving many of these problems. Today the flying surgeon is well equipped to carry out all the routine measures that are necessary at an active aviation base or field. The Army has splendid training schools and they are able to supply the officers necessary for that Service.

The Navy has only recently established its own school for aviation medicine and is now turning out its own specialists. This is not enough, however. So today the Navy is going ahead with correlated research in all the fields that have to do with the physiology of flying. In a very few months there will be established at the Naval Medical Center in Bethesda one of the most complete laboratories of its kind in this or any other country. Here the various problems will be worked out not only by the Navy, but by any of the civilian organizations that come under our present National Research setup. In other words, we expect to see a very splendid effort made in research, and the Navy expects to play its part in cooperating completely.

We are now engaged in an attempt to find a safe and satisfactory oxygen supply apparatus. Up to this time we can not say that there is a completely satisfactory one which will function perfectly at altitudes above 30,000 feet. We hope to see this solved in the very near future. Today planes fly at 400 miles an hour; during the last war it was seldom that we saw a plane that could do more than 150 miles an hour. Our long-range bombers and patrol planes are capable of sustained flights of over 24 hours, with large crews and complex missions. Night operations are extensive, and operations at sea from carriers and other ships are a special consideration. The net result is that the stress encountered in flying has greatly increased; in fact, modern aircraft performance has come to exceed the capacity of the human element at the controls.

The Navy is turning to great advantage the fine work that has and is being done by the officers and men attached to the Diving Unit at the Washington Navy Yard. Behnke has proved beyond the shadow of a doubt that the same problem that meets the diver, that is, that of bends, is the same as that of aero-embolism which the aviator sometimes encounters in the higher levels. We know now that we are able to overcome the bends, and when we can find a satisfactory supply apparatus for the pilot and other members of a ship's crew, the hazard of aero-embolism will be speedily eliminated.

The Navy has engaged the assistance of the U. S. Public Health Service Research Laboratory at Bethesda in the studies on oxygen supply apparatus and aero-embolism. We have conducted extensive field studies



at the Air Station at Pensacola, under the direction of Dr McFarland of the Harvard Fatigue Laboratory This work was done under the joint sponsorship of the National Research Council and the Navy

We in the Navy have been doing dive bombing for a period of four teen to fifteen years, and here again we have much to learn Dive bomb ing and other aerial maneuvers in high speed planes subject the pilot to tremendous stress of five or six times normal gravity This means that a pilot is subjected to five or six times his weight Under these conditions he is helpless to a great degree The important effect is upon the circulation resulting in inadequate blood supply above the heart level and a resulting failure of vision, blackout, and even temporary unconsciousness if sustained This is an important matter requiring the most serious consideration

The subject of fatigue must be vigorously attacked I feel that the man who solves this question and tells the professional world what fatigue is will have done an untold service to mankind

The most disturbing problem we face in active aviation today is that resulting when the mental stability of the pilot becomes unsettled This calls for the most careful and diplomatic handling, and unless the symptoms are apprehended in the very early stages most serious complications result We are now making a very definite attempt to find proper means of evaluating the actions and symptoms of our pilots who are under the strain of combat flying We know what the British are going through and we know that a tremendous number of men have been sent away from active duty, never to return, because of the inability of the medical profession to return them to a normal state

We are investigating the proper type of recreational facilities that should be provided for the pilot when he is on active duty and when he is in the recreational area We are going further than this We are looking into the subject of convalescent hospitals, which will not be hospitals as we understand them but rather on the lines of a summer hotel where the aviators will be under the common sense supervision of medical officers properly trained and equipped to handle this delicate work

Extended night operations have stressed the importance of good night vision and have therefore, laid open the whole question of dark adaptation in the selection of pilots for this work, particularly with regard to standards for selection of personnel and improvement in the cockpit illumination Since night flying and night bombing are of such great importance in warfare today this is a lively topic

Because in the past certain eye diseases were due to vitamin de



ficiencies, and are today for that matter, some individuals thought that by crowding certain of these vitamins into the aviator he would immediately see much better in the dark. We are going ahead with studies on dark adaptation and in conjunction with civil organizations have established certain interesting facts. I think I can safely remark that the vitamin theory is of very little use in helping a man to see better at night.

We have a great deal to learn about the close relationship between general reaction time, depth perception, and the part peripheral vision plays with these two. I hope to see work carried out whereby these three things are linked together, since it will go a tremendous distance in making the pilot much more efficient in aerial combat.



(15 miles). The balloon which carried the oxygen pressure gondola had a volume of 3,700,000 cu. ft. and used helium for the lifting medium. Air samples, obtained near the ceiling of this flight, showed that the proportion of the component gases in the atmosphere was about the same as that found at sea level.

The oxygen pressure gondola is not of practical value, either for civil or military aviation. It may be said that the pressure suit, which the British Royal Air Force used, is not likely to have military exploitation because the increased pressure makes the wearer almost immobile. However, the pressure cabin aeroplane, which was developed first in 1920, has been successfully used in stratosphere flying, about 20,000 feet, flying from New York to the west coast and it has been also employed in military operations above 40,000 feet during the present world war. In this type of aeroplane, the pressure in the closed cabin is generally set at that which would be present at an altitude of 8,000 feet. Although the individual is quite comfortable in these cabins, the great danger in military aviation is that a leak in any part of the pressure cabin, at an altitude of 40,000 feet, would precipitate acute oxygen-want with unconsciousness, and also might result in the development of air bends. It seems likely, none the less, that in the future there will be more and more expert development of pressure cabins, both for civil and military purposes. At the present time the vast majority of aeroplanes which travel at high altitudes cannot employ pressure. The pilot breathes oxygen-enriched atmospheres up to 100% oxygen to compensate for the diminished pressure in the atmosphere. The passengers, both civil and military, are pursuing a safe course in inspiring oxygen at altitudes above 10,000 feet, as will be made clear in the succeeding section.

#### **Physiological Factors Involved in High Altitude Flying**

The fact that engineers have built planes that climb above 55,000 feet and travel faster than 7 miles a minute has confronted the physiologist and the physician with four major problems, (1) oxygen-want, (2) air bends, (3) pressure disturbances in the ears, nasal accessory sinuses and abdomen, and (4) the effects of centrifugal force.

The most fundamental physiological factor which is involved on ascending to a high altitude is the expansion of the gases in the atmosphere in inverse relation to the pressure. In the expansion of 1 liter of gas at various altitudes, it will be seen that at 18,000 feet, one liter of gas has expanded to two liters and at 33,700 feet to four liters, and at 42,000 feet to six liters. Since the volume of the chest remains constant, the expanded air in the lungs contains a progressively smaller amount of



the individual air constituents. Thus, one liter of air at 42,000 feet would only contain one sixth as much oxygen as it did at sea level. Breathing 100% oxygen cannot compensate for altitudes above 34,000 feet, since expansion of an atmosphere of pure oxygen ultimately results in such dilution that an insufficient number of oxygen molecules exists in the lungs to maintain a normal pressure of oxygen. The number of oxygen molecules in a given space becomes progressively smaller as the pressure is lowered. The water vapor pressure in the lungs remains almost constant, and the pressure of carbon dioxide persists, moderately lowered by increased ventilation. The sum of water vapor and  $\text{CO}_2$  pressure must be subtracted from the total pressure, and what is left consists of the oxygen pressure. Thus, at a high altitude in which the individual was breathing fairly hard although inspiring 100 per cent oxygen, the total of water vapor and carbon dioxide pressures might be  $47 + 35$ , or 82 mm Hg. If the barometric pressure was 138 mm Hg, the pressure of oxygen in the lungs would be 138 minus 82, or 56 mm Hg even while he was inhaling pure oxygen.

One of the most apparent effects of ascending to a pressure equivalent to 40,000 feet in a chamber, is the distention of the abdomen. The gas in the intestines will expand, for example, from one quart to over four quarts, which would make the individual uncomfortable were it not for the fact that, as the gas expands, it generally passes through the intestinal canal and is gotten rid of in large amounts. If some obstruction is present in the colon, severe pain ensues, and the pressure is promptly lowered if it is feasible to do so.

#### Oxygen-Want

When an individual has ascended to an 18,000 feet altitude, a unit volume of air in his lungs has expanded to two volumes of air, and contains only one half as much oxygen as was present at sea level. Breathing air at 18,000 feet is equivalent to breathing 10% oxygen at sea level, which is approximately one half the concentration of oxygen in the atmosphere, i. e., 20.93 per cent. The pressure, therefore, of oxygen in the alveoli of the lungs falls as the altitude is increased. The pressure of carbon dioxide in the alveoli of the lungs remains relatively constant up to the point where the individual begins to hyperventilate. This may begin as low as 10,000 feet. The  $\text{CO}_2$  pressure is apt to fall gradually until an altitude of about 15,000 feet is reached when, due to a sharp increase in pulmonary ventilation necessitated by the diminishing oxygen pressure, it may rapidly fall to 25 mm Hg at an altitude of 18,000 feet. At this point the human subject is suffering both from severe oxygen



want and from alkalosis, the latter produced by a disproportionate loss of carbon dioxide from the lungs.

If we were now to measure the oxygen saturation of arterial blood at various altitudes, we would find that the blood becomes progressively less saturated with oxygen as the altitude is increased. Thus, at 16,000 feet, the saturation of arterial blood with oxygen would be about 78 per cent. At sea level, the hemoglobin in arterial blood is 95 per cent saturated. Paul Bert was the first to point out that the primary effect of altitude on the human being was due to the diminished pressure of oxygen in the atmosphere. One of his subjects, Tissandier, undertook a balloon flight with Crocé and Sivel in 1875. The latter part of the flight was described by Tissandier as follows: "Body and mind become feebler. . . . There is no suffering. On the contrary, one feels an inward joy. There is no thought of the dangerous position; one rises and is glad to be rising. I soon felt myself so weak that I could not even turn my head to look at my companions. . . . I wished to call out that we were now at 26,000 feet but my tongue was paralyzed. All at once I shut my eyes and fell down powerless and lost all further memory." The balloon ascended to 28,820 feet and then came down of its own accord. Tissandier recovered but his two companions were dead. Since that time many investigations have been conducted at high altitudes, particularly in high mountains, and by laboratory experiments in which either the percentage of oxygen or the pressure of oxygen was lowered. It becomes clear that for proper activity of any organ, oxygen must be supplied at a pressure which is not far below that present in the atmosphere.

### **The Symptoms of Oxygen Deficiency**

The early signs of oxygen-want are a more rapid beating of the heart and an increased volume of breathing. After some hours' exposure to a moderate altitude, such as 12,000 feet, characteristic symptoms appear, namely headache, nausea and lassitude. If the exposure is more prolonged, or the altitude is higher, more severe symptoms take place, such as vomiting, fever and pronounced mental impairment. When lack of oxygen is very severe, the pulse becomes rapid and feeble, consciousness is greatly impaired and finally lost, and progressive damage is done to the central nervous system, heart and other organs.

Within recent years, the effect of *moderate* altitudes has been studied carefully, primarily because of the fact that in civil aviation aeroplanes were being flown at altitudes of from 10,000 to 12,000 feet. Investigators have shown that mental impairment unquestionably takes place at altitudes of 12,000 feet and over, when the average subject is exposed



for a period of three or more hours to this atmosphere. There is a decrease in memory, reason, judgment and emotional control. Some of us believed that pilot error was in some instances caused by impaired judgment due to oxygen want at these altitudes. A prolonged series of hearings were held before a subcommittee in the U. S. Senate in 1936 to investigate certain aeroplane accidents and notably the one in which Senator Cutting was killed. In the book then issued on the topic *Safety in Air* the possible effects of oxygen want on the pilot's judgment was not discussed. This is all the more remarkable because Pilot Bogan had been in the air between nine and ten hours flying to altitudes as high as 10 000 to 12 000 feet. It is now recognized that pilot fatigue is not simply due to the stress and strain of conducting an aeroplane through uncharted areas in the sky but may be the result to a considerable extent of mild degree of oxygen want. On May 1 1941 the Civil Aeronautics Board inserted the following amendment in its regulations: Post 61 743 Oxygen Apparatus and its Use. No air carrier aircraft shall be operated in scheduled air transportation at an altitude exceeding 10 000 feet above sea level continuously for more than thirty minutes nor at an altitude exceeding 12 000 feet above sea level for any length of time unless such aircraft is equipped with an effective oxygen apparatus and an ample supply of oxygen available for the convenient use of the operating crew and proper use is made of such apparatus.

It is important to remember that certain tissues are sensitive to oxygen want and others are relatively insensitive thus the extremities may be deprived of oxygen for periods of an hour and a half by complete closure of the arterial blood supply and thereafter may be used with completely normal function. However a guinea pig dropped in an atmosphere of nitrogen dies of convulsions within fifty to sixty seconds. Human beings may die or suffer from severe brain hemorrhage when exposed to complete asphyxia for five minutes. The brain is the organ most sensitive to oxygen want and impaired mental concentration begins after exposure for several hours to altitudes between 10 000 and 12 000 feet. In exact investigation changes in visual function have been observed at altitudes below 10 000 feet. Between 12 000 feet and 18 000 feet the effects on mentality are similar to alcohol intoxication. In the larger percentage of human subjects feelings of well being take place with hilarity and increased talkativeness. In a smaller group depression, slowness of response and sleepiness occur.

The organ which is the next most sensitive to oxygen want appears to be the heart. An increase in pulse rate is one of the earliest signs of



ascending to high altitudes, and in many instances the T wave of the electrocardiogram has been shown to be depressed at altitudes as low as 8,000 feet. In patients with coronary artery disease, the inhalation of low oxygen mixtures, corresponding to altitudes of 15,000 to 18,000 feet, has been made use of as a test of a constricted coronary artery. In many instances characteristic anginal pain, with accompanying electrocardiographic changes such as depression of the ST segment and the T wave, are produced during a period of twenty minutes' inhalation of these low oxygen atmospheres. This is obviously of importance when we consider the transport of patients by aeroplane at altitudes of 12,000 feet, if there is not provision for the continuous inhalation of oxygen.

The pathological changes caused by severe oxygen-want affect primarily the blood vessels; these consist of dilation of the capillaries, with increased permeability, hemorrhage, edema, and peri-vascular infiltration. Both large and small hemorrhages have been observed and affect the nerve cells in the cortex of the brain, as well as the corpus striatum and the medulla, also. Hemorrhages have also been found in the heart muscle and the mitral valve, and in the lungs, kidneys and other organs.

#### **Compensating Physiological Changes in Man at High Altitudes**

The physiological changes which take place at high altitude depend upon whether the ascent has been made gradually, as in train transport to high mountains, or whether the ascent has been swift, as in aeroplane travel. Consider the effect of continuous residence at an altitude such as 14,000 feet. On the day after ascent there is a decrease in blood volume which is more marked on the second day. At the same time there is a rise in the flow of blood through the heart. It will be seen that the increase in cardiac output two days after arrival at 14,000 feet is about 100 per cent. This is accompanied by a 20 per cent contraction in blood volume, which gives the appearance of an increase in the number of red blood cells. Although the number of red blood cells per unit of circulating blood has been increased as a temporary mechanism to carry more oxygen, there is not an actual increase in red cells until about the fifth day when stimulation to the bone marrow (as a consequence of the oxygen deficiency) results in an outpouring of new red corpuscles. The cardiac output, which is increased to furnish an increased amount of oxygen per unit of circulating blood, gradually decreases from the second to the fifth day, when the increase in hemoglobin and red blood cells has taken place.

The individual has also compensated in other ways, such as an elevated volume of breathing with a resultant increase in the elimination



of carbon dioxide, a greater elimination of alkaline salts through the kidney, and perhaps also a redistribution of blood to those organs which are most oxygen sensitive

### **The Oxygen Dissociation Curve**

Much of our understanding of the oxygen supply to the body tissues has been derived from knowledge concerning the oxygen dissociation curve of hemoglobin. The hemoglobin in red corpuscles in arterial blood holds and releases oxygen in a special way, which is primarily dependent on the pressure of oxygen to which it is exposed.

About nineteen twentieths of the oxygen carried in the blood is bound to hemoglobin and one twentieth is found in physical solution. A pressure of 100 mm Hg of oxygen results in an oxygen saturation of the hemoglobin of about 95 per cent, and as the blood is exposed to a lower oxygen pressure, the oxygen saturation of hemoglobin curves downward, with especial swiftness below a pressure of 50 mm Hg. There is also an alteration of the amount of oxygen that is held by hemoglobin, depending on the pressure of carbon dioxide to which the blood is exposed. Thus, it will be seen that when blood has an oxygen saturation of 70 per cent and is in contact with 5 mm  $\text{CO}_2$ , the oxygen partial pressure will be approximately 22 mm Hg. If, however, blood at a saturation of 70 per cent is exposed to 40 mm  $\text{CO}_2$ , the partial pressure of oxygen will then be about 44 mm Hg. This is a fact of great importance in regard to tissue respiration. As the blood circulates in the capillaries it is exposed to carbon dioxide which makes it give up oxygen more readily. As the blood passes into the lungs, when the carbon dioxide is liberated the hemoglobin takes on relatively more oxygen.

One of the most constant effects of exposure to high altitude is the increase in the rate and depth of breathing. As a consequence of the increased volume of ventilation, there is a fall in the pressure of carbon dioxide of the lungs. As more carbon dioxide is eliminated from the lungs the blood becomes less acid. It has been shown that the effect of carbon dioxide described above is due to its acid quality, addition of  $\text{CO}_2$  makes blood more acid and elimination of  $\text{CO}_2$  renders it more alkaline. The effect of the decreased acidity of the blood is, therefore, that the hemoglobin holds on to oxygen more tightly and the tissues suffer from a decreased tension of oxygen, even though the oxygen saturation of the blood is at a relatively high level. Thus, in experiments in which cardiac patients have breathed 10 per cent oxygen the pH has been observed to rise from 7.44 to 7.54, due to loss of  $\text{CO}_2$ .



This would mean that the tissues would be exposed to a pressure of 36 mm. Hg of oxygen, instead of 40. A more alkaline condition of the body, alkalosis, produces a form of oxygen-want due to shifting of the oxygen dissociation curve to the left. The state of alkalosis has been shown to result in constriction of peripheral blood vessels, so that ischemia is also produced. In other experiments in patients with coronary artery disease, the inhalation of small percentages of carbon dioxide, together with 10 per cent oxygen, has prevented the occurrence of anginal pain, by preventing the loss of carbon dioxide. In summary, it may be said that excessive elimination of  $\text{CO}_2$  from the body does harm in at least two ways, (a) by making the hemoglobin in the red cell more alkaline and thus give up oxygen less readily in the tissues, and (b) by producing constriction of small arteries and arterioles and decreasing the flow of blood to the tissues. Alkalosis may, therefore, be a serious complication of acute oxygen-want at high altitudes, and aggravate tissue anoxia.

### **The Treatment of Oxygen-want at High Altitudes**

If an individual is exposed to a high altitude on a mountain, such as 10,000 to 14,000 feet, an illness called "mountain sickness" takes place, which is in most cases apt to disappear on the fifth or sixth day of residence. It is only in severe reactions, or in patients with cardiac or pulmonary disease, that inhalation of oxygen is necessary. The physiological compensations discussed above gradually alleviate this illness. Our primary problem, however, concerns itself with conditions of anoxemia which occur in aeroplane ascent, namely with acute oxygen deficiency. The ideal treatment of oxygen-want is administration of oxygen in such percentage as will completely overcome the anoxemia (or lowered oxygen tension in the blood) produced. At 10,000 feet the arterial blood may be 90 to 92 per cent saturated with oxygen, depending upon the volume of breathing. In our opinion, aviators who are piloting planes at altitudes of 10,000 to 12,000 feet should inhale oxygen from the start to the end of their flight. In this way their judgment is preserved to the peak of its efficiency and danger of accident is made less. Furthermore, the pilot himself is less apt to suffer from fatigue and from the recurring effects of oxygen-want which appear to result in a special form of nervousness called by Armstrong "aeroneurosis."

The inhalation of 40% oxygen will compensate for all altitudes which are apt to be met with in civil aviation, in the main altitudes of 10,000 to 20,000 feet. Of special importance at the present time is the provision of an adequate supply of oxygen for aviators flying in military expeditions. The most recent practice appears to be the inhala-



tion of oxygen in very high concentration, notably 100 per cent, especially for altitudes between 25,000 and 35,000 feet. In exposure to altitudes up to 33,000 to 34,000 feet, the arterial blood is 95 per cent saturated with oxygen during the inhalation of pure oxygen. As the altitude increases from 35,000 to 40,000 feet, the arterial oxygen saturation falls to approximately 80 to 85 per cent. This degree of oxygen deficiency is comparable to that which a pilot might experience at 14,000 feet without oxygen. Unquestionably, there are signs of impairment of judgment at 40,000 feet even when breathing 100 per cent oxygen, but these are not sufficiently great as to incapacitate him, and military objectives may be accomplished.

It would be obviously preferable to have his judgment unimpaired, if it were possible to do so at this altitude. Research with this goal in mind is in progress. It does not appear that adding carbon dioxide to an oxygen enriched atmosphere increases the adaptation of individuals to very high altitudes. Although carbon dioxide stimulates the breathing and increases the dissociation of oxygen from hemoglobin, and also prevents alkalotic ischemia, the inhalation of 100 per cent oxygen appears to be better than mixtures of carbon dioxide and oxygen, in recent studies made in our laboratory. If an individual is breathing 2 per cent  $\text{CO}_2$  in a mask at sea level, this percentage is increased at one fifth of an atmosphere to 10 per cent carbon dioxide. In order to administer the equivalent of 2 per cent carbon dioxide at sea level to an individual at 40,000 feet, he would have to inhale approximately 10 per cent carbon dioxide and 90 per cent oxygen. In studies made in a low pressure chamber at the Aviation Research Laboratory in New York, we have seen no advantage from adding carbon dioxide. It must be borne in mind that the provision of 10 per cent carbon dioxide means a corresponding loss in the amount of oxygen inhaled, the subject breathes 90 per cent oxygen instead of 100 per cent. The increased ventilation which is stimulated by carbon dioxide does not apparently offset the loss in the mass of molecular oxygen inspired. Up to the present time, the best method of treating oxygen deficiency at very high altitudes is to supply oxygen in a concentration of 100 per cent. Physiological investigations are being carried out in the attempt to make possible a more normal oxygen tension to the tissues of the brain, heart and other organs especially to the oxygen sensitive organs.

#### Recent Investigations Concerned with Resistance to Anoxia

Since military flying has been conducted at altitudes above 35,000 feet at which anoxia inevitably takes place with its consequent impair-



ment of mental and bodily function, we have been interested in the study of those factors which might increase resistance to oxygen-want or damage resistance to oxygen-want.

A factor which decreases the resistance to anoxia was found to be excessive smoking. The smoke from cigarettes yields 1 per cent carbon monoxide by volume, from pipe tobacco 2 per cent, and from cigars about 6 per cent carbon monoxide. Thirty subjects were studied who inhaled the smoke of twenty cigarettes from the time of arising to about half-past three in the afternoon. Approximately half of the subjects tested had a carbon monoxide saturation of between five and ten per cent after smoking twenty cigarettes. The effect of carbon monoxide in displacing oxygen from hemoglobin has long been known. At sea level this degree of carbon monoxide in the blood is probably not of much harm except in those individuals who are sensitive to CO poisoning, or in patients who have latent or overt disease of the cardiac or respiratory systems. It seems likely in some individuals that the headache of the "morning after" may be partly due to carbon monoxide poisoning. However, in aviators who are flying at altitudes between 10,000 and 12,000 feet, without oxygen, or in those who are traveling above 35,000 feet even with the inhalation of 100 per cent oxygen, this degree of carbon monoxide poisoning will tend to aggravate the anoxia caused by high altitudes.

The second factor which was studied was the effect of experimental thyroidectomy on rats. It was found that normal animals die at an altitude of 34,000 feet during a two hour exposure, whereas the animals who had had their thyroid removed were alive up to an altitude of 42,000 feet. This is an experimental demonstration of the fact that a lowered requirement of oxygen increases tolerance to high altitudes. It would seem likely that pilots whose basal metabolism is 20 per cent above normal would withstand very high altitudes less well than those whose basal metabolism was 20 per cent below normal. Furthermore, measures may be found which will make possible a temporary lowering of the oxygen consumption and if this turned out to be the case, these measures would make possible an ascent to higher altitudes than those now feasible. In addition, individuals who are to be exposed to very high altitudes should avoid undue stimulation of their metabolism before ascent to high altitudes, such as that produced by ingestion of a heavy protein meal.

Other investigations are in progress in the attempt to modify the physiology of man so that he may better adapt himself to very high altitudes since this has become a military necessity. In addition, im-



ascending to high altitudes. At the present time there is no other method of preventing aero embolism and it may be that this procedure will become more frequently used than it has up to this time.

The fact that oxygen is utilized by the tissues and present in the blood as discussed in the section on the oxygen dissociation curve is responsible for the fact that aero embolism could not take place primarily as result of an oxygen bubble. Even during the inhalation of 100 per cent oxygen the pressure of oxygen in the tissues themselves would be only about 60 mm Hg. The oxygen physically dissolved under these circumstances would be 2 cc per 100 cc of blood and after it was consumed the hemoglobin would then become deprived of an additional amount of oxygen probably 3 to 4 cc per 100 cc of blood passing through the tissues. The pressure of oxygen would fall in the tissues to that equal to venous blood namely less than 60 mm Hg. This is in contrast to nitrogen which is present in the tissues of the body at a pressure of approximately 515 mm Hg. When a bubble has been formed by nitrogen coming out of solution it is then likely that oxygen will diffuse into it as well as carbon dioxide and water vapor since the pure nitrogen bubble will have no counteracting partial pressure of the other gases.

In the members of our group at the Aviation Research Laboratory the symptoms of air bends has taken place in four of five people who have been exposed to altitudes of 40 000 feet even though 100 per cent oxygen was breathed for periods of three quarters of an hour before exposure to the low pressure. It is probable that a longer exposure to inhalation of 100 per cent would make the peril of aero embolism less frequent. In laboratory investigations it is always possible to descend to the atmospheric pressure and thus immediately stop the symptoms.

#### **Pressure Disturbances in the Para Nasal Sinuses and the Ear**

The middle ear and the frontal ethmoid and maxillary sinuses connect with the nose or the back of the throat by passages which are ordinarily able to receive an interchange of air pressure without great difficulty. However if these openings are closed by a swelling of the mucous membrane such as might occur in an acute cold there may be an increased pressure within the tube or sinus during ascent in an airplane. Under these circumstances the air under increased pressure (for example in the middle ear) is apt to push itself out through the eustachian tube. Some discomfort is experienced but the condition is not as severe as that which takes place when an individual comes down



from a high altitude to sea level. Under these circumstances, the air within the middle ear is under a decreased pressure and if the pharynx is acutely inflamed, an infolding of the mouth of the eustachian tube takes place with obstruction to the entrance of air. As a consequence, the pressure on the inside of the drum becomes relatively less, in comparison to the pressure on the outside of the middle ear. In that event, pain and hemorrhage may take place and if the ear drum is forced in with a marked amount of pressure, rupture of the drum is produced. In most cases the eustachian tube can be opened by repeated swallowings and yawnings, or, if necessary, by holding the nose tightly and compressing the cheeks with a closed mouth. Under certain circumstances if an equalization of pressure has not taken place and pain results, the individual may reascend to the high altitude where the pain first occurred and the pain will disappear. A slow descent may then result in a gradual equalization of pressure on two sides of the drum. In many cases, inhalation of helium-oxygen mixtures during descent, or afterward, causes relief of pain in the middle ear since the smaller helium molecule may diffuse through the eustachian tube more easily than a molecule of nitrogen. The effect of pressure variations in themselves, such as from one-fifth of an atmosphere to 15 atmospheres, is probably negligible, provided that equalization of pressure takes place gradually in the air spaces of the ear and the sinuses, or any other region containing air.

### **Effect Due to Centrifugal Force**

The effects of centrifugal force are produced by a change in the direction of motion, either upward or downward or to one side. It is believed that if man is adequately protected against the pressure of wind, he can withstand any velocity, provided that the aeroplane is traveling at a sufficiently constant rate and that the direction is not changed. We are moving all the time at a velocity of 12.4 miles per second with the earth around the sun without being aware of it, obviously because our surroundings are moving with us.

Acceleration may be defined as a change of velocity. When this change introduces stress, as in a linear or centrifugal change, a disturbance of a characteristic nature may be produced. Since in Newton's law " $F$  equals  $MA$ " then " $A$  equals  $F$  divided by  $M$ ." In other words, linear acceleration is proportional to force and inversely proportional to mass. Since weight constitutes a measure of the force of gravity and varies with the mass of the body, it has become convenient to view the force of gravity as a unit of measure for acceleration, which has been



denoted by the symbol *G*. Accelerations which produce forces upward on the airplane, perpendicular to its line of flight, have been called positive accelerations and those directed downward are called negative accelerations. The most important effect of acceleration is retarding the return of blood to the heart. The direction of the force exerted on the body has a bearing on the magnitude of the effect, since the largest columns of blood appear in the great vessels entering the auricles.

When the return flow of blood is interfered with the visual system, including the retina and the optic nerves are particularly apt to be impaired since these mechanisms are especially sensitive to anoxia. The symptoms of positive acceleration have been described in terms of *G*s. Thus, at five *G*s the body is beyond the control of the muscles except for slight movements of the arms and head. Coma takes place at six to eight *G*s and concussion is said to be produced at twenty *G*s, or an acceleration of 640 feet per second acting for a fraction of a second. The most important factor appears to be the effect of hydrostatic pressure on the decreased filling of the heart. It has been shown by x rays of monkey hearts that exposure to five and seven *G*s result in an almost complete absence of the cardiac shadow due to the failure of filling of the heart. The pathology of concussion is of considerable interest since some believe that the essential lesion is fat embolism of the finer cerebral blood vessels. Loss of consciousness would then be ascribed to anoxia of the cerebral tissues and an additional reason for administering oxygen. The treatment of the dangerous effect of undue accelerations is largely to attempt to prevent them. Accelerations in the transverse axis of the body are least harmful and, if it were practical to place the pilot in a position perpendicular to the line of the aircraft's maximum force this would be an advantage. With positive acceleration since the principle damaging effects are due to a drop in blood pressure and a loss of blood supply to the brain, anything which would increase this pressure would tend to overcome the ill effects. Tensing the abdominal muscles has been reported to be of some value. In addition mechanically increasing the intra abdominal pressure by a belt has been used and seems valuable. It is said that by means of a belt the tolerance of an individual for positive acceleration may be increased to two or three *G*s. The best effect is obtained when the belt is inflated to a pressure of about 75 mm Hg for half a minute before the exposure to the expected acceleration.



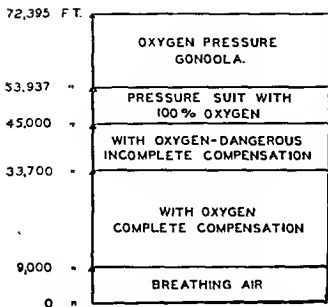


FIG. 1.—Methods of reaching high altitudes.

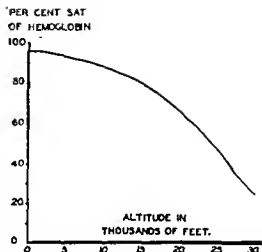


FIG. 4.—Oxygen saturation of arterial blood at varying altitudes.

FIG. 2.—Expansion of gases at various altitudes.

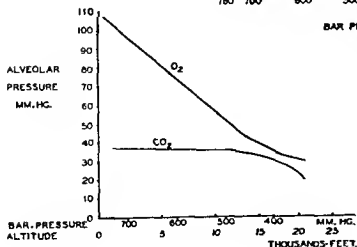
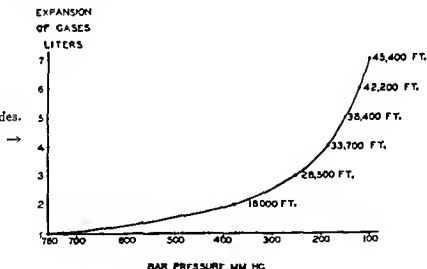


FIG. 3.—Alveolar oxygen and carbon dioxide pressures in a human subject while breathing air at varying altitudes.



FIG 5—Effect of residence at 14,000 feet, on blood volume, total red cells and cardiac output

BLOOD VOLUME  
PER CENT OF NORMAL

TOTAL RED CELLS  
PER CENT OF NORMAL

CARDIAC OUTPUT  
LITERS/MIN

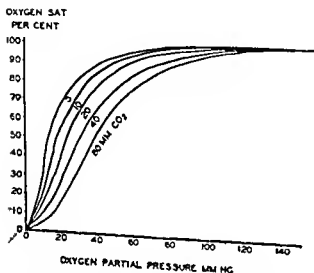
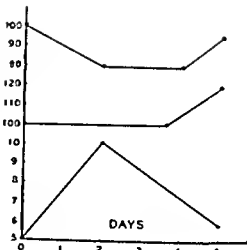


FIG 6—Per cent saturation of hemoglobin with oxygen with different partial pressures of oxygen and carbon dioxide

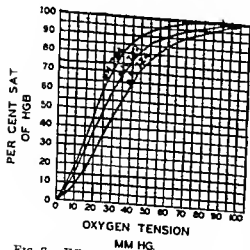


Fig 7—Effect of changes in pH on the oxygen saturation of hemoglobin at various oxygen tensions

From Behnke

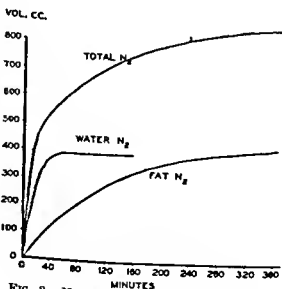


Fig 8—Nitrogen elimination in a human subject while breathing 100% oxygen



**Summary**

Since engineers have made flying possible at altitudes above 50,000 feet and at speeds over 400 miles an hour, the physiology of man has been challenged in several important respects. We have reviewed the following physiological factors:

1. *Oxygen-want.* The existence of impairment in mental functioning at altitudes of 10,000 to 12,000 feet or over, is an indication for the continuous use of inhalation of 40 per cent oxygen at these altitudes. From 25,000 to 35,000 feet inhalation of 100 per cent oxygen is advisable in civil as well as military aviation. Above 35,000 feet anoxemia persists even during the inhalation of 100 per cent oxygen, and above 40,000 feet dangerous disturbances in cerebral function may occur. Oxygen pressure suits have been impractical up to the present time for combat flying because of the degree of immobilization which they produce. The pressure cabin may be the ultimate answer for flying at very high altitudes, but at the present time there are few in use. They suffer from the obvious danger that the slightest leak at altitudes of 40,000 feet or over would cause almost immediate unconsciousness due to anoxia, as well as the probable development of *aero-embolism*.

2. *Air embolism* may occur when the pressure is reduced more than one-half that of the atmosphere. In actual experience signs of *aero-embolism* have taken place at barometric pressures equivalent to altitudes of 25,000 to 35,000 feet, and more commonly especially if the exposure to the lowered atmospheric pressure is prolonged. The most common symptoms are pain in the joints, especially the knee joint, and itching sensations in the skin. More dangerous symptoms are due to emboli to the lungs, with chest pain and pulmonary edema, or emboli to the spinal cord, with paralysis of the extremities. The symptoms are generally relieved when the pressure is increased to that of the atmosphere or to that equivalent to an altitude of 18,000 feet. The best prophylactic treatment is the inhalation of 100 per cent oxygen for a period of two hours. Nitrogen desaturation is more quickly obtained when exercise accompanies the inhalation of pure oxygen.

3. A difference in pressure in the nasal sinuses and the outside atmosphere, or in the middle ear and the external atmosphere, may result in pain of the affected parts. During a swift ascent the air in the eustachian tube is generally able to pass out of the orifice because of the increased pressure. However, in the presence of swelling of the mucous membrane, such as may occur in an acute cold, descent of the aeroplane rapidly causes a valve-like obstruction of the eustachian tube



with marked increase in external pressure on the outside of the eardrum and a decreased pressure within the eustachian tube. Inadequate pressure neutralization during descent may cause pain, hemorrhage, or even perforation of the drum. The best method of treatment is gradual descent with repeated swallowings and yawnings, or forcible compression of the air within the oral cavity by blowing with the nose and mouth closed. Inhalations of 20 per cent oxygen and 80 per cent helium may be helpful during or after descent, since the smaller helium molecule may diffuse into the eustachian tube.

4 The effects of centrifugal force were briefly mentioned. A disturbance in consciousness and impairment of vision are apt to be the two most frequent symptoms. The limit of human endurance is a centrifugal force which has been described as five "G's" lasting for a period of three seconds. Failure of the heart to fill with blood is one of the most important results of the forces produced by positive acceleration. Wearing a special belt which results in increased pressure on the abdomen for a limited period of time appears to be of considerable help.

5 Patients with coronary artery disease should not travel at altitudes above 10,000 feet without continuously inhaling oxygen because of the possibility of precipitating precordial pain or cardiac failure. Patients with pulmonary emphysema and fibrosis may suffer a marked increase in dyspnea when traveling at these altitudes without oxygen. In patients who are being treated by pneumothorax, the expansion of the gas into the pleural cavity may produce symptoms of increased pressure and lead to untoward results.

6 Some of the physiological problems reviewed, which are now of special importance in military aviation, may become important in the civil aviation of the future, such as aero embolism and the effects of centrifugal force as well as the consequences of severe anoxia. The spread of substratosphere flying in pressure cabins in commercial aviation will tend to reduce the occurrence of the symptoms of anoxia as well as the pressure disturbances in the middle ear and the accessory nasal sinuses, but the effects of a sudden loss of pressure will require special study in order that accidents of this nature will be rare and, if they do occur, expertly treated.

Recent investigations in our laboratory have shown that resistance to oxygen want at high altitudes may be increased or decreased by altering the physiology of man. Thus, excessive inhaling of tobacco smoke may result in mild carbon monoxide poisoning which aggravates anoxia. Total removal of the thyroid in rats increased resistance to low baro-



## Principles of Aviation Medicine

metric pressures; the majority of thyroidectomized animals survive at altitudes 8,000 feet higher than normal animals. There is an urgent need for studies which will reveal the mechanism of man's resistance to high altitudes and how it may be aided by physiological as well as mechanical means.

The swiftness with which high altitude flying has become a fact has confronted the physiologist and the physician with many new problems that need further investigation.

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# PHYSIOLOGY AND HIGH ALTITUDE FLYING: WITH PARTICULAR REFERENCE TO AIR EMBOLISM AND THE EFFECTS OF ACCELERATION

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## I. Introduction

"Ye who listen with credulity to the whispers of fancy, and pursue with eagerness the phantoms of hope; who expect that age will perform the promises of youth, and that the deficiencies of the present day will be supplied by the morrow; attend to the history of Rasselas, prince by Abissinia.

"Rasselas was the fourth son of the mighty emperour, in whose dominions the Father of waters begins his course; whose bounty pours down the streams of plenty, and scatters over half the world the harvests of Egypt.

"According to the custom which has descended from age to age among the monarchs of the torrid zone, Rasselas was confined in a private palace, with the other sons and daughters of Abissinian royalty, till the order of succession should call him to the throne."

And the account goes on to say that the palace of Rasselas was in a spacious Abyssinian valley into which came artists and men of science to advance the culture of its happy Utopian population. It so happened one year that a famous artist and engineer came to the valley to settle and the young prince made frequent visits to his house. One day the engineer told Rasselas:

"I have been long of opinion, that, instead of the tardy conveyance of ships and chariots, man might use the swifter migration of wings; that the fields of air are open to knowledge, and that only ignorance and idleness need crawl upon the ground (1, p. 35). . . . He that can swim needs not despair to fly; to swim is to fly in a grosser fluid, and to fly is to swim in a subtler. We are only to proportion our power of resistance to the different density of the matter through which we are to pass. You will be necessarily up borne by the air, if you can renew any impulse upon it, faster than the air can recede from the pressure (1, p. 36). . . .

"The labour of rising from the ground," said the artist, "will be great, as we see it in the heavier domestick fowls; but, as we mount higher, the earth's attraction, and the body's gravity, will be gradually diminished, till we shall arrive at a region where the man will float in the air without any tendency to fall: no care will then be necessary,



but to move forwards, which the gentlest impulse will effect" (1, p. 37-38).

At this juncture Rasselas thought his engineer had gone astray and interjected,

"All this . . . is much to be desired, but I am afraid that no man will be able to breathe in these regions of speculation and tranquility. I have been told, that respiration is difficult upon lofty mountains, yet from these precipices, though so high as to produce great tenuity of the air, it is very easy to fall: therefore I suspect, that from any height, where life can be supported, there may be danger of too quick descent" (1, p. 39).

Rasselas, although unconvinced, was interested and urged the engineer to proceed. This he did under one condition, namely, that Rasselas would divulge to no one the secret of making wings.

"Why," said Rasselas, "should you envy others so great an advantage? All skill ought to be exerted for universal good; every man has owed much to others, and ought to repay the kindness that he has received."

"If men were all virtuous," returned the artist, "I should with great alacrity teach them all to fly. But what would be the security of the good, if the bad could at pleasure invade them from the sky? Against an army sailing through the clouds neither walls, nor mountains, nor seas, could afford any security. A flight of northern savages might hover in the wind, and light at once with irresistible violence upon the capital of a fruitful region that was rolling under them. Even this valley, the retreat of princes, the abode of happiness"—this Abissinia—"might be violated by the sudden descent of some of the naked nations that swarm on the coast of the southern sea" (1, p. 41).

And so Rasselas promised secrecy. The wings were made and the wings were tried, but, like Icarus, the inventor fell into the sea, for he lacked the motive power to flap his wings; and Rasselas rescued his engineer from a watery grave.

Thus did Samuel Johnson in 1759 depict the problems of aviation medicine and their relation to warfare. Rasselas was something of a physiologist by temperament, his friend was an inventive engineer, but the engineer was also a realist, for he insisted that certain things can not for the moment be told to the world lest it jeopardize the "security of the good."

If the history of aviation were to be written one would come quickly to appreciate Dr. Johnson's astonishing prescience in characterizing so vividly the developments of modern aeronautics. The modern aeronautical engineer has placed primary emphasis upon design, upon the



attainment of speed and quick manoeuvrability; in some modern combat planes virtually everything has been sacrificed to gain these two objectives—everything sacrificed including the pilot. It is no secret, for example, that until very recently some of the new bombers designed to fly 35,000 feet were so cold inside at that altitude as to make it quite impossible for a crew to function effectively for more than a few minutes.

The second development in modern combat flying has arisen from recognition of the need for protecting the pilot, and at long last aviation engineers are getting together with flight surgeons—and even with physiologists—recognizing that the physical limitations of the pilot are quite as important as the physical characteristics of the machine, and that both must be considered in designing and operating combat aircraft. I propose to deal with three phases of the problem, all essentially physiological, affecting pilot performance at high altitudes, (i) temperature, (ii) aero-embolism and (iii) effects of high acceleration.

## II. Temperature

Under standard atmospheric conditions the temperature at 38,000 feet is 55° below zero Fahrenheit; above that stratospheric level the temperature falls but little. The pilot, or the gunner in the open turret, exposed to such a temperature for 8 hours with a wind velocity of 20 m.p.h. is worthless as a gunner; occasionally indeed he has turned out to be a cake of ice.

There have been many studies in war and in peace time of the influence of cold on human performance. In a word, exposure to intense cold for a sufficient duration to cause perceptible lowering of the rectal temperature makes motor performance slow and inaccurate, and cerebral activity, as indicated by the ability to solve simple problems or to follow simple directions by radio, is gravely impaired. As with nearly all problems involving stress, some individuals are much more affected than others.

The designing engineers have given us planes that will fly to 35,000 and even 40,000 feet, but at first they largely forgot the pilot and the crew, believing that inconveniences from extremes of temperature could be taken care of by clothes from Quartermaster Corps. In single-motored fighter planes, there is little trouble from cold, even in the high altitude ranges, since the pilot sits behind the engine and the cockpit receives direct warmth from it; but in all larger twin-motored or four-motored planes, especially the long-range bombers, the bomb bay is generally open to the outside air and the heating arrangements, especially in the American-made planes, were not only inadequate, but in some of the



better known the heating facilities are virtually useless heaters having been put in the top instead of the bottom of the fuselage. Enormous quantities of heat are available from the exhaust of the long range bombers and with little alteration in basic design the exhaust could be made to heat any strategic point in the plane including the gunner's position. The gunner is more exposed to cold than any other member of the air crew for in most planes his station in the blister receives the full blast of outside air from the horizontal machine gun aperture and in a long mission the gunner may be at his position for eight hours or more at an altitude of 20 000 feet at which level the outside temperature would be  $25^{\circ}$  below zero.

Numerous proposals have been made to combat low temperatures e.g. electrically heated suits boots and gloves and there have been many designs of other types of clothing. Most acute however is the need for an oxygen mask and an oxygen line of supply that does not freeze up during prolonged exposure to low temperatures. The Army and Navy have recently released for manufacturers their criteria for oxygen supply systems in which they insist that the oxygen mask and accessory supply valves must not freeze up in one hour with temperature— $40^{\circ}$  Centigrade in the face of a wind velocity of 10 m.p.h. at an altitude of 37 500 feet. Every mask commercially available at the present time freezes up solid after about 10 minutes of such punishment. Those who have seen the popular film *Dive Bomber* will have had vividly portrayed the consequences of a frozen system of oxygen supply.

And there are also many vicious circles in connection with cold and high altitude. If very heavy clothing is worn the crew must do more work in moving about and hence require more oxygen. If the oxygen supply clogs or freezes at 35 000 feet especially that of a crew member moving heavy bombs he falls unconscious within 15 seconds or less and the duties of other crew members are generally of such a nature as to prevent their giving prompt assistance. I can not describe in detail how the problem of cold is being met here or in England but one can say this that the flight surgeon is still forced to employ many awkward expedients—all of them I hope temporary—until the heating engineers have solved their phase of the problem which includes heating as well as ventilation and also watching for carbon monoxide and other toxic gases.

### III Aero Embolism

Some of the faster interceptor planes may gain altitude at the surprising rate of a mile a minute this brings them at that rate of ascent



is maintained, from sea level to 35,000 feet in roughly 7 minutes. Actually, the rate of ascent is inevitably slower in the rarefied air, but it is stated in the newspapers that some of our new fighters have attained altitudes of 36,000 and 37,000 feet within 10 minutes of the time they took off. The pressure of air at 34,000 feet is a quarter of that at sea-level atmosphere—190 mm Hg instead of 760 mm. An aviator arising to 34,000 feet thus subjects himself to the same relative decompression as that experienced by a diver ascending from 100 feet of water—which is equivalent to 4 atmospheres—to the surface level. If a diver ascends too rapidly, nitrogen bubbles tend to form in the tissues and blood stream, and in the same way aviators who subject themselves to rapid decompression are likely to experience the symptoms of bubble formation in their tissues. To divers and to caisson workers, the painful syndrome has long been known as "bends" because the excruciating character of the pains causes those affected to "double up."

The tendency of bubbles to form in the blood under conditions of decompression was first observed by Robert Boyle in the course of those celebrated experiments in which he weighed the air, determined the reciprocal relationship between volume and pressure, and compared combustion with respiration (1662). Boyle observed that when freshly drawn blood was placed in a decompression chamber bubbles were evolved on the surface of the blood as air was being sucked out of the chamber. He asked himself whether these bubbles did not represent the fraction of the air normally taken up when blood passes through the lungs. If this were true, he argued, bubbles should appear in the blood vessels of animals subjected to rapid decompression. Although Boyle's premise was not wholly correct he was led through this reasoning to make one of the most important observations in the history of our subject. Small bubbles do, in fact, appear in the circulating blood of animals subjected to decompression and this is how Boyle described it in a short note in the *Philosophical Transactions* for September 12, 1670.<sup>2</sup>

"Note, that the two foregoing Experiments were made with an Eye cast upon the inquiry, that I thought might be made; Whether, and how far the destructive operation of our Engin upon the included Animal, might be imputed to this, that upon the withdrawing of the Air, besides the removal of what the Airs presence contributes to life, the little Bubbles generated upon the absence of the Air in the Bloud, juyces, and soft parts of the Body, may by their Vast number, and their conspiring distention, variously streighten in some places, and stretch in



others, the Vessels, especially the smaller ones that convey the Bloud and Nourishment, and so by choaking up some passages, and vitiating the figures of others, disturbe or hinder the due circulation of the Bloud? Not to mention the pains that such distensions may cause in some Nerves, and membranous parts, which by irritating some of them into Convulsions may hasten the death of Animals, and destroy them sooner by occasion of that irritation than they would be destroyed by the bare absence or loss of what the Air is necessary to supply them with, and to shew how this production of Bubbles reaches even to very minute parts of the Body, I shall add on this occasion (hoping that I have not prevented my self on any other) what may seem somewhat strange, what I once observed in a *Piper*, furiously tortured in our Exhausted Receiver namely that it had manifestly a conspicuous Bubble moving to and fro in the waterish humour of one of its Eyes [p 2044]



## *Physiology and High Altitude Flying*

Commander Behnke severe "bends" developed between 25,000 and 28,000 feet without preoxygenation. With 45 minutes preoxygenation "bends" did not develop until 30,000 feet; with 90 minutes preoxygenation the ceiling was raised to 34,000 feet; with 3 hours to 37,000 feet and after 5 hours preoxygenation the "bends"-susceptible subject withstood 40,000 feet for 2 full hours without experiencing symptoms.

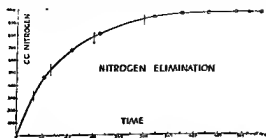


FIG. 1.

(b) *Helium.* Oxygen for prolonged administration is hazardous because of its toxicity. Nitrogen can be removed as effectively from the body of a helium-oxygen mixture as with pure oxygen. Since helium is only one third as soluble in fat as in nitrogen, the quantity of gas available for bubble formation, especially in the bone marrow, which comprises as much as 90 per cent. fat, is greatly reduced. If a human being were saturated with helium, instead of nitrogen, it would require only 90 minutes of oxygen inhalation to eliminate dissolved helium in contrast to the 5-hour period for nitrogen elimination. Commander Behnke believes it would be practicable to have bomber pilots in a ready room filled with an atmosphere of oxygen and helium prior to flight. So far, however, this proposal has not had service trial.

*Preselection for high altitude service.* The susceptibility to "bends" varies enormously in different individuals, and little is known as yet of the basis for the differing susceptibilities. The younger age groups are less susceptible than the older, and any one having an injury to a joint is prone to develop "bends" at the site of injury. Pilots in the age group of 18 to 24 can often withstand prolonged exposures to altitudes as high as 40,000 feet without developing the symptoms. Behnke and others have recently stressed this point, and it has now become possible on the basis of decompression chamber tests to single out for the high altitude squadrons those pilots who can stand, say, 35,000 feet for 4 hours without developing untoward symptoms. At least 50 per cent. of the young adult population fall into this category, and it is probable that with training the percentage will be even larger. Hence, if pilots are selected through preliminary decompression chamber tests as fit for



high altitude operations, bends ceases to be a serious military problem. All the preventive measures elucidated by Commander Behnke and others, even for those who appear to be unsusceptible to bends," such as taking oxygen from the ground up, ascending slowly and indulging in the limited amount of exercise possible in the cockpit of a plane, are also recommended for observance.

It is possible that certain drugs may diminish 'bends' susceptibility, but as yet there is no panacea for protecting a susceptible subject except for a full 5 hours of preoxygenation.

#### IV. Effects of Acceleration

An aircraft flying along the curve of any circle, whether in pulling out of a dive, a tight turn or a diving spiral will have acting upon it from the center of the circle a centrifugal acceleration which varies directly as the square of the linear velocity and inversely as the radius of the circle. The actual weight attained by a body during acceleration is the product of the mass and the acceleration expressed in terms of the normal attraction of gravity, *i.e.*, 1 *g*. At a centrifugal acceleration of 7 times the force of gravity (7 *g*), a pilot weighing 180 pounds normally would have a weight so long as the 7 *g* is sustained, of 1,260 pounds. Every tissue in the body takes part in this increase in weight and as the current RAF *Manual* puts it at 6.9 *g* the blood becomes as heavy as molten iron. During such acceleration the weight of the hydrostatic column of blood is too great for the heart to cope with on the arterial side and venous blood fails to be returned to the heart from regions of the body below the cardiac level. Hence there tends to be a pooling of blood in the abdomen and lower extremities and failure of the cerebral circulation. The effect of diminished circulation to the retina of the eye manifests itself in graying, and, finally, in ultimate failure of vision—giving the phenomenon of 'blackout'. When vision goes consciousness is likely to fail shortly thereafter.

There is a time factor in acceleration as important physiologically as the absolute magnitude of the centrifugal force itself. The average young adult can withstand sitting in the upright position 5 *g* for 45 seconds. He might also stand 7 *g* for 2 seconds, but no normal adult can withstand 7 *g* for 7 seconds without complete loss of consciousness. This means that neurons of the brain are so intimately dependent upon their supply of oxygen that when this is withdrawn by centrifugalizing the blood away from the head consciousness lapses, usually within 5 seconds.

The capacity to withstand acceleration varies in different individuals,



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and in the same individual at different times. Test pilots have found that an alcoholic spree of an evening considerably diminishes their tolerance for positive acceleration the next day. Relative anoxia, such as may occur in high altitudes when the oxygen supply is inadequate, likewise diminishes resistance to acceleration, and it is likely that the level of the blood sugar is similarly important. In recent German literature various expedients have been recommended to assist the pilot to withstand positive acceleration. These may be enumerated briefly.

1. *Full stomach.* In the recently published diary, "I was a Nazi Flier," there is a diverting chapter on aviation medical research in Germany in which it is stated that all resistance on the part of pilots to being experimented upon was overcome when it became known that the "doctors" had recommended that the pilots of Stuka dive bombers should have a large beefsteak before going off on a mission! From other sources (e.g., Ruff and Strughold, 1939, 4) it is clear that the German flight surgeons insist that an empty stomach diminishes tolerance to high acceleration. When the stomach is full the visceral blood vessels are also distended so that more blood can not readily enter them—so runs the German explanation. Blood chemistry, no doubt, also plays a part in determining resistance to *g*.

2. *Carbon dioxide.* Use of 5 or 6 per cent. carbon dioxide, which through increasing the cerebral circulation is said by the Germans to increase resistance to acceleration by 1 to 2 *g*.<sup>4</sup> This is doubted by other authorities.

3. *Vasoconstrictor drugs.* Any pharmaceutical agent which increases the "tone" of the capillary wall improves one's *g* ceiling. Pituitrin, adrenalin and adrenal cortical hormones have all been mentioned in this connection, but precise data concerning these are not available.

4. *Pneumatic belts.* Mechanical constriction of the abdomen as well as of the lower extremities has also been proposed in both the German and English literature to minimize the rush of blood from the head to the visceral bed and the lower extremities. Of these mechanical devices, pneumatic belts and pneumatic trousers have been most under discussion. The Germans state that a pneumatic belt may increase *g* tolerance by 1 to 1.5, but no one of the present belligerent countries has permitted publication of detailed reports concerning the actual effectiveness of this equipment.

5. *Water suits.* The Germans have also reported on a "water suit"



designed for the prevention of blacking out, and while they claim it notably improves resistance to positive acceleration they state that it is unsatisfactory for other reasons To quote Grow and Armstrong<sup>5</sup> (pp 276-277)

The water suit is a closely fitted water proof garment which is worn next to the skin What little space is left in the suit after it is put on is filled with water or other suitable fluid This causes the flier to 'float' in the suit and during accelerations the water presses on the body equally in all directions As a consequence the normal effects of acceleration are replaced by a uniform compression of the body which, it is estimated, could be tolerated without difficulty up to 15 *gs* or more

6 *Posture* In a recent paper by Ruff<sup>6</sup> in *Medizinische Klinik* the problem of posture in relation to acceleration was discussed The Germans it appears favor a crouching posture with flexion of the legs against the abdomen as one particularly suited for protection of the pilot against acceleration This would bring the hydrostatic column of blood in the leg veins nearer to the heart level If the pilot lies supine or prone at the end of a dive bombing manoeuvre, he is also less subject to negative accelerations but in these postures he is unable to see out or to manoeuvre his plane without special redesigning of the cockpit and the cockpit controls

It should be noted that all factors tending to improve the body's resistance to positive acceleration are those which tend to keep blood in the head From this it may be concluded that the phenomenon of blacking out and loss of consciousness which may occur within 5 seconds of the beginning of the acceleration is probably due solely to acute anoxia and can not be attributed to any direct effect of acceleration *per se* upon the cortical neurons

## V. Conclusion

Many other phases of aviation medicine might be discussed but since there are certain topics that can not be gone into fully at the present time—having in mind Rasselas' Security of the good I hope however, that I have been able to indicate some of the more important developments as well as the intensely fascinating character of the problems encountered

I believe that the successful solution of several problems in aviation medicine will determine in large measure the outcome of the present war



## *Physiology and High Altitude Flying*

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# THE NEWER CARDIOLOGY AND AVIATION MEDICINE

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Clinical medical practice has always eventually gained much from the hard won experiences of military medicine. In the first world war, for example, the cardiovascular problems associated with neurocirculatory asthenia were so fully developed that the concept of an unstable heart and blood vessel system in young adults became better understood and appreciated in general practice.

In the present war the role of air power has so completely altered military strategy that many previously held concepts have, as a result, been changed or abandoned, likewise the development of aviation medicine has shown that many well known theories concerning the cardiovascular system both in health and disease must be changed in the light of experiment and experience in this new field of medical science.

Aviation cardiology differs from clinical cardiology in that the former is largely concerned with a struggle against the physical factors of a hostile environment while the latter contends with infectious and other pathological problems besetting the heart and blood vessel systems. Aviation cardiology can be defined as the study of the cardiovascular system under an altered environment in which the factors of barometric pressure, temperature, velocity, and change of acceleration all play dominant roles. In clinical cardiology these factors are rarely, if ever, of any practical importance.

We will consider briefly some of these physical factors. First, barometric pressure, at sea level this is 760 mm Hg. At 5,000 feet, 632 mm, at 10,000 522 mm, at 18,000 379 mm or  $\frac{1}{2}$  atmosphere, at 25,000 282 mm, at 33,000 196 or  $\frac{1}{4}$  atmosphere. Atmospheric pressure is important not only because of the physical pressure phenomena which take place in soft yielding tissues and membranes but also because of the available oxygen present for respiratory function.

At sea level with a pressure of 760 mm the oxygen content of the air is about 20% with a partial pressure of 159 mm Hg. This is normal. At 18,000 feet or  $\frac{1}{2}$  atmosphere the partial pressure will be reduced one half or 79 mm. In terms of sea level oxygen this would mean a drop to about 10%. However, a correction factor due to the moisture of the alveolar air in the lungs reduces this available oxygen still more. Thus when the partial pressure of the inspired oxygen is reduced by  $\frac{1}{3}$  the alveolar, partial pressure is reduced to  $\frac{1}{2}$ , at 50,000 feet with



an atmospheric pressure of 86 there would be no partial pressure of oxygen in the lungs at all.

This brings us now to the problems of insufficient oxygen for normal metabolic requirements. *Anoxemia* is a term used to describe the lack of sufficient oxygen in the blood stream and is a well recognized symptom in clinical cardiology. *Anoxia* is a condition in which there is an oxygen deficiency in the body tissues and is rarely seen in clinical cardiology. Anoxemia can be produced very quickly; it also can be removed very rapidly by increasing the available oxygen supply. Anoxia is a chronic state of tissue oxygen want and may not be removed even if more oxygen is made available for respiration. Exposure to lowered barometric pressure over a period of time may thus cause tissue changes which are not reversible; this is true particularly of the brain as well as the heart.

The problems of gas exchange are primarily functions of the cardiovascular system and the lungs; when there is oxygen want, the heart either has to speed up its volume output or arterial pressure must be increased to compensate for the drop in partial oxygen pressure. In either case, the heart is forced to work harder and will be under increased strain. But the heart itself is especially sensitive to oxygen want and unless there is an adequate coronary flow physiological compensation will not take place and congestive failure rapidly develops. Under ordinary circumstances a given heart may be able to handle any circulatory demands made upon it, but with reduced oxygen availability it may completely fail. This was one of the first lessons learned from aviation cardiology; from it was developed the anoxemia test for myocardosis and early forms of coronary disease in clinical cardiology.

Another factor of a lowered barometric pressure is concerned with the law of variable pressure constants; translated into terms of clinical medicine it means that the pressure on two sides of a soft tissue or membrane must be equalized or the structures will be displaced from the area of the higher pressure to that of the lower. This is no better seen than in the gastro-intestinal tract; assuming intestinal gas at sea level to be at 760 mm and equal to the outside air, at 18,000 feet the outside air would not be  $\frac{1}{2}$  that inside the intestine and distention will be developed, sometimes to a painful degree. Changes of pressure are noted in the middle ear and aviation otology is a rapidly expanding new specialty concerned with this problem.

The heart and blood vessels are a closed system containing a fluid, the blood. With an outside pressure of 760 mm Hg the heart normally maintains an intravascular pressure of about 125 mm Hg. With a decreasing barometric pressure, arterial pressure will fall since both



the heart and the vessels will expand. Either the volume of the circulating medium must be increased or the systolic blood pressure must rise in order to compensate for this differential pressure change. Here again only a thoroughly compensated cardiovascular system with a maximal reserve power can adjust itself to the barometric changes encountered in military aviation.

Next in the order of new environmental changes is that of temperature and particularly low temperatures. At 75° F a pilot's basal metabolic requirements may be plus 8%, at 32° it will rise to plus 14%. At 0 temperature it will be plus 20%. At 25° below zero it will be plus 35% and at 48° it will be nearly plus 50%. Thus low temperatures complicate the oxygen problem, not only will the pilot need much more oxygen than normally but there will be less oxygen available to him because of decreased partial pressure of the air. Loss of body heat is also enhanced by the effect of skin exposure to the surrounding air, the faster the flow of the air over the body surface the greater the loss of heat. Thus the outside temperature may not actually be very low, say about 40° but the air flow in an exposed cockpit plane may be 200 or more miles per hour. The effect will be a great rise in basal metabolic oxygen rates, when both low temperatures and air flow occur together the basal rate may rise as high as 75% above normal. In terms of increased oxygen demand this may constitute a hazardous problem.

Finally, a word about the physiological effect of velocity and change of acceleration upon the cardiovascular system. This is still the great research problem in aviation cardiology, gas exchange and temperature investigations have been carried out in great detail in every country during the past 22 years since the last world war. They are largely questions of vital concern not only to the military services but also to commercial aviation interests, they are problems which can be studied in the laboratory. Artificial altitude chambers exist in great abundance in all universities and research institutions and nearly all of the physiological questions of oxygen and temperature reactions can be answered without even leaving the ground. Velocity and acceleration changes have, up till now, been studied under actual flying conditions and are hence more dramatic.

The keynote of modern military aviation is speed. It is no military secret to say that large bombers can cruise at 250 miles per hour. Fighter planes are worthless unless they can make 350 miles, some reach and maintain speeds as high as 550. These speeds are calculated for horizontal flying and ordinarily manifest no additional physiological prob-



lems to the cardiovascular system in addition to those previously described as the result of altitude.

With the advent of dive bombing, however, strange and hitherto unknown factors and forces come into play and an entirely new nomenclature has been developed. "Black outs," "air bends," "redding out," "head lightning" and "dead legs" are but a few of the more popular terms coined by pilots to describe certain acceleration syndromes. Over all of these new words hangs the mystic and terrible letter, capital "G."

What is this G which has earned the respect and fear of every high speed pilot? It is merely an old formula with a new meaning; it is taken from Newton's law of universal gravitation

$$F = G \frac{M^1 M^2}{d^2}$$

In linear acceleration the formula becomes

$$A = \frac{F}{M}$$

In curved flight, acceleration depends on rate of change of direction and the velocity and can be expressed

$$F = \frac{MV^2}{r}$$

Force under these conditions is a unit of measure and is called "G," and contains the forces of centrifugal pull as well as the forces of simple gravity. In other words G is the number of times the centrifugal pull out multiplies a body's weight. Thus if the pilot weighs 150 pounds a pull out of 3 G will force him down in his seat at a pressure of 450 pounds.

Upward acceleration of the plane causes positive G and downward causes negative G; it must be remembered that the forces set up in the body are directly opposite to the forces of the plane. In a plane going up in the direction of feet to head, the inertia in the body acts from head to feet.

Translated into terms of power diving, for example, a pull up at 175 miles per hour after 10 seconds amounts to 9.3 G; a 150 pound pilot thus weighs 1,380 pounds at that moment. What happens to the various tissues and structures of the body under such terrific stress? There are four general types of structures which are affected; soft supporting tissues, bony tissues, organs supported within the body cavities, and the body fluids. It can be readily understood that lightly supported tissues due to their inertias tend to lag behind and may be torn off or



severely damaged. Organs may be displaced upward or downward at great pressure, the abdominal viscera may, for example, crowd the diaphragm and thorax and thus embarrass respiration and heart action.

Of the fluid systems like the cerebro spinal and circulatory, hydrostatic factors immediately occur. Since most of the large blood vessels run longitudinally in the body direct hydrostatic action will pull the blood into the lower part of the body and abdomen at the expense of the head and will also hinder the venous return to the heart. Both of these factors will cause a marked anemia of the brain and sensory organs particularly vision which is sensitive to anoxemia. A negative pull of  $G$  will cause opposite hydrostatic phenomena with a rise in cerebral vascular pressure augmented now by an increased cardiac output.

Let us consider the symptoms of various degrees of  $G$ . First is a simple plus  $G$  which is merely the force of gravity and equal to the weight of the falling body. At  $2 + G$  there is an awareness of pressure against the seat of the plane and a heaviness of the hands and feet which feel much larger. At  $3$  and  $4 + G$  these symptoms increase and it becomes difficult to move the hands and feet. The skeletal muscle gets involuntarily tense as the body tends to resist compression in the vertical dimension. The trunk and head unless supported tend to bend down. At  $5 + G$  the body is beyond the control of the muscles and one is physically helpless. There is a heavy dragging sensation in the thorax from traction on the viscera. The blood leaves the head and face and there is either partial or complete loss of vision, this is called a blackout. There is painful cramping of the arms and legs and breathing becomes difficult even with oxygen because the thorax is crowded by the abdominal viscera.

From  $6$  to  $10 G$  there is increasing symptoms of cerebral anemia with complete unconsciousness but with a memory of blinding flashes called head lightning which may persist for long periods after the acceleration is decreased. The pulse rate may rise as high as  $180$ , blood pressure usually drops. At  $8.3 G$  Armstrong showed systolic pressure to fall as low as  $20$  mm.

Most of the symptoms caused by positive  $G$  are ordinarily recovered from after a short period of normal environment, although mental confusion, headaches, vertigo and visual disturbances may persist in susceptible individuals. This stands in direct contrast with the effects of negative  $G$  forces in which blood is driven from the lower parts of the body upwards into the thorax and chest. At a  $1$  negative  $G$  which would be the equivalent of the body hanging downward, there is moderate upward displacement of the abdominal and thoracic organs with



congestion of the face. At negative 2 G-these symptoms are increased but at negative 3 G the head is highly congested and throbs with pain. At negative 4 G the head seems about to burst, the eyes appear to be bulging, and the visual field becomes red. This is known as "redding out" and may persist for some time. Experiments on humans beyond negative 5 G have not been carried out due to irreversible changes which take place in the brain and other organs. While unconsciousness does not ordinarily take place, the mental confusion which occurs may require days for complete recovery.

Exposure to 3 to 4 negative G's for even a few seconds may do more permanent damage than exposure to 7 positive G's for 10 seconds; in experimental animals at 5 negative G's the cardiac sphincter of the stomach will open and the contents will be ejected through the mouth. Massive cerebral hemorrhage occurs in a few seconds at 6 to 7 negative G's.

In dive bombing terrific speeds are employed; for example at an initial speed of 110 miles per hour, in ten seconds the terminal velocity will be 1,098 miles per hour with a pull out G of plus 5. With an initial speed of 220 miles at the end of ten seconds the velocity would be 2,197 miles per hour with a pull up of 10 G. With a "black out" occurring at 5 to 7 plus G's, it is small wonder that many fatal crashes occurred before these physiological facts were known. Early in the European war it was recognized that great individual susceptibility occurred in the physiological response to this G factor; the younger the individual the more easily it was overcome. Hence the surprising youth of the 1940 Stuka dive bomber pilots; these lads were 16 to 18 years old and were employed for this task not because of any scarcity of German pilots as was previously reported by the French press, but because they could withstand these tremendous environmental forces with less hazard than the older pilots.

In the newly developed dive bombers used by nearly all air forces at this time, automatic pull up is an integral part of the plane's mechanism and fatal crashes are less common and should be entirely eliminated, but the "black out" still persists and offers challenge to medical research; it is still necessary for the pilot to remain conscious and mentally alert enough to manipulate intricate machine gun apparatus and bomb shell release equipment. Here the physiological effect of G may render worthless the most highly developed plane design and well trained pilot personnel.

We come at this point to one of the most important research problems in aviation cardiology and without releasing any military secrets,



it may be said that medical science is developing suitable measures to combat these hazards. It can also be said that this effort is not without some permanent value in clinical cardiology; just as the study of oxygen want in aviation medicine has led to a better understanding and treatment of certain cardiovascular disorders in civilian life so the investigation of the G factor will bring great promise in the treatment and prevention of cerebral vascular disease. Apoplexy, hemiplegia, and paralytic stroke as a group come within the six great causes of death in this country; if this great number can be diminished by the research now proceeding in aviation cardiology, two great causes will have been served.



## HYPOTENSION IN AVIATION

With a Review of 159 Fatal Crashes

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It is well known that the vasomotor system is the most sensitive part of the body; and, while the selection and care of the aviator from the cardiovascular standpoint have proved an interesting subject for investigation and study, recent investigation has shown that more emphasis should be placed on hypotension as a factor in assessing standards of fitness for aviation training. We have been prone to look upon persistently low blood pressure as entirely compatible with a normal state of well-being and health, but whether it is compatible with the stress and strain incident to the violent flying indulged in by naval aviation, especially in wartime, is another matter.

Aviation within the past few years has undergone such enormous development in the design and construction of airplanes making for increased power, stability, speed, climb, and maneuverability that one might think the human machine—the flier—had been somewhat overlooked. On the contrary, there have been remarkable advances in aviation medicine, the results of which have overwhelmingly shown in a lowering of aviation accidents since the late World War. It is particularly gratifying to note that, despite the increased scope of naval aviation activities in the fleet during the past year, the accident record was 31 percent less than during the fiscal year 1938.

The problems that confront the flight surgeon still are the problems that confronted him 15 years ago, namely, (a) nervous stability or the psychic factor, (b) respiratory, and (c) cardiac efficiency. These are the important factors in the make-up of a naval aviation pilot. The fundamental physiological and psychological consideration of the problems as understood and reported at that time have not materially changed, but a better and more thorough understanding of these conditions has been developed which, it is believed, will be of interest. These problems have been altered somewhat with the increasing power and refinements of aircraft. The psychological aspect is undoubtedly the most important and difficult problem in the selection of a candidate for naval aviation; just what part it plays in hypotension is difficult to say. Improvements in the supply of oxygen for high altitudes have for the present relegated the respiratory factor to the background. With the stress and strain incident to increasing speeds likely to evoke vast forces into action on the bodily mechanisms of the pilot, it has become



necessary to put more stress on the study of cardiovascular efficiency. As Marshall<sup>1</sup> has pointed out, the forward speed that a pilot can endure without discomfort, is far in excess of the speed that any airplane is capable of at present. It is only change of direction, acceleration or deceleration that brings centrifugal forces into play. Furthermore, during these intervals, which may be only a few seconds, the pilot's body mechanism is subjected to these forces which experiments have shown drain the blood from the upper parts of the body. Moreover, from this sudden and rapid change strain is brought to bear in many other ways on the circulatory system during flying. Flack and Bowdler<sup>2</sup> stated that from a consideration of blood pressure records, the conclusion is forced upon us that stress of service in high flying almost invariably produces a low diastolic pressure, due probably to lessening vasoconstrictor tone of the arterioles.

Whatever the cause, hypotension should always be looked upon with suspicion in selecting candidates for aviation. They might be classed with the fainters as potential aviation hazards. However, it is a fact that we have several pilots in naval aviation today with exceptionally low blood pressures, who have been performing their duties in a highly creditable manner while careful and continuous observation has failed to show any objective symptoms to the contrary.

Our present conception of the hypotensives in aviation has been almost exclusively due to Treadgold<sup>3</sup> who made 20,000 calculations in the Royal Air Force as a frame for British standards. He noted that estimations of systolic pressures alone may be misleading. Where a pressure of 125/100 would be suggestive of pathology, one of 155/75 in a young adult under excitement of a medical examination is usually of no significance. Opposite interpretation would be placed on such cases in many instances by a medical examiner relying on systolic pressure alone. It would appear therefore, that diastolic pressures between 70-80 mm of Hg regardless of the systolic reading could be classed as of no significance in healthy young adults. However, a diastolic reading from 80 to 90 mm of Hg would be open to question and anything above 90 mm of Hg diastolic should seldom be accepted for aviation training without renal investigation.

#### What Is Hypotension?

Hypotension may be defined as a condition of the circulation in which the systolic or diastolic blood pressure or both falls below a certain figure. Most authorities agree and accept 110 mm Hg as the lower level of systolic blood pressure. Osler and McCrae<sup>4</sup> regard any



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thing below 110 mm. Hg as hypotension. Likewise, Cecil<sup>5</sup> is in agreement with these findings, but neither of these authors defines diastolic standards. Others regard a systolic pressure of 110 mm. Hg and a diastolic pressure of 66 mm. Hg as the lower limit in males, but there is apt to be some variation. MacWilliam<sup>6</sup> considers a systolic pressure below 110 mm. Hg and a diastolic pressure below 66 mm. Hg as definite hypotension; Miller<sup>3</sup> gives 105 mm. Hg for systolic and 60 mm. Hg for diastolic as bottom levels; Snell<sup>9</sup> quotes U. S. Army flying standards that systolic pressures less than 105 mm. Hg are disqualifying for flying in all cases. The standard used in the Royal Air Force for some time is to consider any systolic pressure below 110 mm. Hg and a diastolic below 70 mm. Hg as evidence of hypotension.

We have no established disqualifying standards for hypotensives in the United States Navy. Regulations governing blood pressure in general are quoted as follows: "Systolic blood pressure if the examinee is over 25 years of age, should not persistently exceed 145 mm. Hg; if examinee is 25 years of age or under, systolic pressure should not persistently exceed 135 mm. Hg. The diastolic should be roughly two-thirds of the systolic." From the foregoing it will be observed that we have no definite standard by which we can classify hypotension in aviation as regards the lower limits of systolic and diastolic pressure. In examining candidates for flight training I have qualified several candidates whom other flight surgeons now consider definite hypotensives and questionable aviation material for military purposes.

It would appear, therefore, that most authorities agree 110 mm. Hg systolic and 70 mm. Hg diastolic should be the lower limits. This standard will be used as a basis in this discussion. The exact level of the systolic pressure is not difficult to obtain yet it is apt to fluctuate due to emotional or other causes and is not usually considered as valuable as that of the diastolic pressure which may be more difficult of estimation. Kilgore<sup>10</sup> stated that although the auscultatory method for estimating diastolic blood pressure was the best available, in approximately 10 percent it was impossible to determine it accurately. The difficulty increases, especially with a person with a very low diastolic pressure. The lower the pressure the harder it is to estimate correctly. In fairness and justice to the examinee, one has to record many readings over several days to be absolutely sure of his result.

### **Essential Hypotension**

Essential hypotension is a rather unsatisfactory name applied to a symptom complex in certain individuals with a persistently low blood



pressure It may be associated with a group of subjective symptoms such as dull headache, dyspnea on exertion, palpitation, vertigo, easy fatigability, inability to concentrate, and giddiness on change of posture The condition appears to be rare Croll and Duthie<sup>7</sup> could find records of only 18 cases Other cases have been reported by Alvarez and Roth,<sup>11</sup> Chew, Allen and Barker,<sup>12</sup> Davis and Davis,<sup>12</sup> Korns and Randall,<sup>14</sup> Langston,<sup>15</sup> and Weis<sup>16</sup>

The patients usually complain of giddiness on assuming the erect posture and examination has shown that the blood pressure, both systolic and diastolic, falls to very low levels on standing At times these patients may show pressures within normal limits if taken in the sitting position and this may be misleading It seems reasonable to infer that between the frank case of essential hypotension and the normal there lies the person whose vasomotor control, although sufficient to prevent symptoms under ordinary conditions, may break down under stress Such conditions of stress are likely to arise in pilots as a result of lowered oxygen tension fatigue, and especially centrifugal force while flying Moreover, the persons most likely to suffer from these effects are those with mild forms of essential hypotension

The problem of detecting susceptible individuals can be studied by the flight surgeon through two methods suggested by Rook and Dawson<sup>17</sup> (a) a study of the blood pressures of those pilots who have reported symptoms of giddiness or actual syncope while flying or otherwise, and (b) a flying test which subjects persons who appear likely to be affected by the stresses of centrifugal force However, the effects of flying tests which produce symptoms can usually be overcome by habituation to flying

### Factors Influencing Hypotension

Factors influencing or causing hypotension are legion, just as there are considerable differences of opinion as to what constitutes hypotension Again the fact is often overlooked that the blood pressure of a normal person may fluctuate widely from day to day, and some times almost from moment to moment Some of the factors which have a direct bearing on hypotension may be summed up as follows

1 It has been observed that in the convalescent or latent stages of certain diseases, faintness or actual fainting in association with a low blood pressure is fairly common, and is apparently due to toxicity This has probably influenced opinion as to the suitability of hypotensives for flying It is questionable if this hypotension with syncope attacks is directly due to a lowering of the blood pressure or is



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simply a manifestation of imperfect vasomotor control.

2. *Hypotension in association with tuberculosis* is relatively common. Tice<sup>18</sup> states that as a general rule hypotension exists in all stages of tuberculosis. This is confirmed by Cecil<sup>3</sup> especially in advanced stages with ulcerative lesions. The difference between lying and standing pressure may be greater than normal. Beaven<sup>19</sup> quotes the cases of 15 U. S. Air Force officers who developed tuberculosis, the average systolic pressure being 106 mm. Hg. However, it appears to be the consensus of opinion among other observers that a low blood pressure is not a reliable sign of tuberculosis.

3. Prolonged mental stress seems to have little effect on blood pressure in healthy adults, the blood pressure varying directly with the pulse rate in these individuals.

4. The endocrine factor has proven to be negligible, except in advanced cases where the endocrine disorder is a disqualification *per se*.

5. Age plays little part as a factor in healthy adults. From 18 to 40 years there is little change in systolic pressure. There may be a rise in diastolic pressure from 18 to 21 years, and a slight fall after 35 years.

6. Body build has little effect if proportionate. The same can be said for weight. Overweight usually carries with it a higher pressure, while hypotension is more common in underweight.

7. Climate affects blood pressure. Roddis and Cooper<sup>20 21</sup> found the blood pressure lower in the tropics than in temperate zones. This was confirmed by the writer in over 500 examinations done on aviation personnel in the tropics. The British military forces in equatorial Africa showed that hypotension occurred in direct proportion to the heat encountered.

8. Cannon and Mott<sup>22</sup> believe that the manifestation of hypotension is the result of fatigue influenced by emotional stress. Based on research and animal experimentation definite changes have been noted in the cortical cells of the suprarenals showing cell membrane rupture, displacement of nuclei, and disappearance of the cytoplasm. The close analogy of the adrenals' influence on the conductivity of brain and liver tissues leads us to believe there is a basis for disfunction of the adrenals caused by psychic conflict. The change in pulse rate and peripheral tone follows as a result of hypotension.

9. Graybiel, Dill, Missiuro, and Edwards<sup>23</sup> found that oxygen lower than 12 percent usually brought about marked blood pressure changes in normal healthy individuals; and, if oxygen tension is gradually lowered, a condition of hypotension supervenes prior to collapse. Similar reactions had been noted several years ago in connection with the re-



breather test, which has become more or less obsolete in aviation examinations. Therefore, anoxemia may be a factor in hypotension that requires more investigation.

10 Hypotension is often observed in severe hemorrhage and in shock due to any cause.

11 Severe anemias and wasting diseases, especially Addison's disease, are frequently attended by hypotension.

12 Myocardial failure may be accompanied by a fall in blood pressure.

13 The emotional component undoubtedly is a factor in hypotension and blood pressure readings in general. This reaction explains at least in part, the low blood pressure readings often found in aviators, who on subsequent examinations show a more nearly basic reading. Athletes who are on a rigid training schedule often show a low average blood pressure. Treadgold's<sup>3</sup> group averaged 103/60 mm Hg with a pulse of 74. This is in agreement with others. This same investigator also collected a non athletic group whose average blood pressure was 102/58 mm Hg similar to the above athletic group in respect to hypotension but whose average pulse rate was 97. Another symptom noted in the latter group was the evident approach to syncope while blood pressure was being taken. This was evidenced by sweating, pallor, cyanosis and dilation of the pupils—factors which were absent in the athletic group. Therefore attention should be called to the fact that while low blood pressure may be a bad omen, it can be the acme of perfection. At the same time, working on the hypothesis that blood pressure rises in reaction to an emotional stimulus, and that the rise is in proportion to the degree of stimulation as measured by introspection or some other means, one is bound to be frustrated by these types of individuals. Even the heart rate in a high percent of these hypotensives may have an average rate comparable, at times, to that found in the athletic group. Braun<sup>24</sup> suggested that it seems more reasonable to assume that the different cardiovascular patterns noted are quantitative reactions, modified in some cases by physiologic considerations. The athletic group maintain a nearly basic blood pressure and pulse which are supported by an efficient physiologic reserve of power to meet an emergency. This reserve is adequate to meet a harmless emotional situation such as a physical examination. The athletic type of hypotensive candidate reacts mildly to the emotional stimulus by a rise in systolic blood pressure. The non athletic and otherwise normal appearing hypotensive candidate lacks the necessary physiologic equipment to carry out the required response, consequently his blood pressure rises



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then drops with dramatic suddenness leaving only the heart struggling vainly with a thready pulse to maintain the defense of the organism.

### **Incidence of Hypotension**

The incidence of hypotension has been rather difficult to estimate. It varies as widely with different authorities as does the estimations of blood pressure readings. Treadgold<sup>3</sup> found 3 percent hypotensives among fit pilots serving with the Royal Air Force from 1927 to 1931 inclusive. Friedlander<sup>25</sup> quoting from various observers noted that the percentage varied from 2.2 to 4.5 in over 9,000 young adults. Chamberlain<sup>26</sup> reported that in 60 medical students and doctors there were 15 with a systolic pressure below 110 mm. Hg.; in 4 of these the diastolic pressure was below 70 mm. Hg.; 2 others had a low diastolic with a normal systolic pressure. Therefore, 17 (28 percent) of the 60 cases were hypotensives. Bramwell and Ellis<sup>27</sup> examined the circulatory systems of Marathon runners and found the diastolic pressure below 70 mm. Hg. in 4 out of the 28 runners. One man with a pressure of 105/70 was third in the race. Rook and Dawson<sup>18</sup> examined the records of 1,000 consecutive candidates for military service between the ages of 18 to 25 years, and they found an incidence of 12½ percent. In most instances hypotension resulted from low diastolic pressures. Furthermore, it was persistent in less than half the hypotensives who were reexamined once. From the foregoing there seem to be wide discrepancies in the figures on the incidence of hypotension.

In the examination of 716 candidates from civilian life for naval cadets for aviation training at Pensacola, Florida, from 1934 to 1937, I found the incidence of hypotension averaged approximately 9 percent, using as a standard a systolic pressure below 110 and a diastolic pressure below 70 mm. Hg. These candidates were all college students of at least 2 years' training. Their ages ranged from 18 to 28 years. All denied a history of syncope, dizziness, or similar manifestations. On closer questioning, however, 2 percent admitted fainting on one or more occasions during their lifetime but stated "it didn't amount to anything." Forty-three candidates whose pulse rate averaged approximately 100 and blood pressure 103/60 showed evidence of syncope while blood pressure was being calculated, as evidenced by sweating, pallor, cyanosis, especially of the extremities, and dilation of pupils. Seven other candidates fainted, losing consciousness for a minute or more while their blood pressure was being taken. No accurate blood pressure readings were obtained in these cases during the fainting episode. It was noted, however, that the blood pressure was below 100 systolic



when the individuals fainted. However, subsequent examination showed these individuals to be hypotensives. The examination was discontinued at this point and the candidate disqualified for flight training. It was particularly noticeable that the above 43 candidates, on being questioned, admitted that they couldn't stand the sight of blood. They further admitted that they couldn't tolerate pain without feeling nauseated and even vomiting at times. Some complained that the sphygmomanometer cuff hurt their arms while taking their blood pressures or that they had pain and tingling in their arm and hand. Changing the cuff or adjusting it or even placing it on the other arm had little effect. They often exhibited considerable apprehension over a cyanosis that occurred below the cuff. None of the symptoms occurred in any of the individuals with a normal blood pressure.

Further observation revealed that the hypotensives were underweight with the exception of three cases whose history and general appearance suggested hypothyroidism. Hypotension appears to be more common in young male adults than is usually imagined. While occasional hypotension is relatively common, many examinations may be necessary to definitely establish persistent hypotension.

#### Relation of Hypotension to Centrifugal Force

As has been stated previously, any known speed can be borne not only in safety, but also in comfort, provided only, that protection is afforded against the wind. The rapid acceleration or deceleration to or from such speed, however, is another matter, as are the effects of centrifugal force incident to sharp turns at high speeds. In pulling sharply out of a dive in violent acrobatics or doing a steep turn, forces many times that of gravity may be encountered. The direction in which the force is applied naturally depends on the position of the body in relation to the center around which the turn is effected. These forces are usually measured in terms of  $G$ —the acceleration due to gravity. The force resulting from any given turn or similar maneuver varies directly with the square of the speed of the plane and inversely with the radius of the circle through which the maneuver is effected. For example, a plane doing a steep turn with a radius of rotation of 300 yards at a speed of 200 miles per hour causes a force of about  $3.2+G$ , at 300 miles per hour with the same radius the force is more than doubled. If, however, the radius of the circle is increased to 800 yards with a speed of 300 miles per hour the resultant centrifugal force is less than  $3+G$ . Let us say then that the effective weight of a 150 pound pilot under such circumstances may reach 750 pounds or more. Blood



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may be forced out of the brain to cause momentary unconsciousness or a "black out" commonly experienced in acrobatic flying and dive bombing. Granting that "black outs" are usually momentary, they can well be fatal under combat conditions with an enemy airman pouring lead or explosive shells at a blind or unconscious pilot. If enough violent flying is indulged in, permanent damage can be done to the central nervous system and the internal organism, as was witnessed a few years ago aboard one of our larger aircraft carriers, when two fatalities occurred within a few hours after carrying out an extensive dive bombing exercise. Actual fractures are not impossible. If and when speeds of 500 and even 600 miles per hour, which designers are talking about, are reached, the beating the human body will take is obvious. Today's top speeds in level flight in still air are not much above 400 miles per hour.

A particularly disastrous group of fatal accidents occurred in the years 1937 and 1938. Some planes actually disappeared without even a trace. What has been the cause of these unexplained crashes? With the present trend toward perfection in mechanical construction and design, it doesn't seem possible that all these fatal crashes can be explained on failure of materiel alone. Certain it is, one has to consider the personnel factor. In fact, in a large percent of these fatal crashes, pilot error was officially given as the primary cause, where subsequent investigation could be carried out; but what about the planes that disappeared without leaving any trace or sign in average or better flying conditions? Was the pilot careless or grossly incompetent? Such I do not believe to be the case in our naval trained pilot. Could not hypotension be a factor in some of these unexplained crashes? I have in mind 5 cadets that I qualified for aviation training, who were all hypotensives, measured by our standards of today. Their average blood pressure, from many examinations, was 105/66. I followed them carefully through primary training and into advanced training. Three of them developed aeroneurosis and air sickness and never completed primary training; one realized his inaptitude and quit the course during the advanced acrobatic training; the other was killed in the advanced course of training while practicing dive bombing. None of them would admit any symptoms of hypotension other than a feeling of insecurity in the air. Aviators are not exempt from the development of such disorders. In fact, the special hazards of their profession give them greater cause to develop them. Furthermore, it is only because we are dealing with a superior group that we do not find a much higher incidence of these disorders. Probably, if more care were used in assessing flying



fitness in regard to hypotensives these disorders and accidents could be further lessened

### **Hypotension In Fatal Aviation Crashes**

The present World War with its high casualty rate from what is known in broad terms as pilot failure is again raising the question as to whether the human mind and body are being taxed beyond their capacity by the speed and complexity of today's airplanes. Reports from abroad indicate that at a minimum for every four pilots killed as a direct result of combat six lose their lives because their judgment becomes faulty or their bodies are unable to stand the strain. Some American authorities insist that pilot failure is accounting for six out of seven deaths in the war. These casualties would include the men officially entered on the records as having been killed in combat. In a good many of these cases it is believed that the pilot was shot down by an enemy because he went to pieces and presented himself as a perfect target for his opponent's guns. While we are endeavoring to select the best physical and mental specimens as candidates for aviation pilot training yet a number of these young men are getting killed in peacetime accidents. Might not cardiovascular instability or hypotension be a cause? Again there is the question whether the human machine is being overloaded due to the complexity of controls of aircraft especially in switching from contact to instrument flying in adverse conditions.

With a view of finding some possible association between hypotension and fatal crashes if any a study was made of the records of 114 naval aviators who were involved in fatal crashes (see table 1). For comparison a study was made of the personnel of 45 fatal crashes which occurred over the same period in connection with student naval aviation training at a naval air station also shown in the table.

This table shows the average age average height average weight and average pulse rate both prone and standing in addition to blood pressure findings. Hypotension is considered here where the systolic pressure is below 110 mm Hg and the diastolic below 70 mm Hg.

In calculating hypotension an estimation of both systolic and diastolic pressures was done. Of the 114 pilots 48 (42.1 percent) showed some form of hypotension. Studying these 48 cases further as to the cause of fatal crashes from the standpoint of materiel failure or personnel (pilot error) it was found from official reports that 40 (83.3 percent) of the 48 cases were due to personnel or pilot error. Comparing the remaining 66 cases which showed a normal blood pressure it was found



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that in 28 (42.4 percent) the cause of the crash was reported officially as due to personnel or pilot error.

**TABLE 1**  
**Personnel Analysis of Fatal Crashes**

	Experi- enced naval aviators	Percent	Student naval aviators	Percent	Total	Total aviators percent
Number of personnel .....	114	....	45	....	159	....
Average age of personnel .....	29	....	25	....	...	....
Body build:						
Height .....	69½	....	70	....	...	....
Weight .....	164	....	154	....	...	....
Average pulse rate of those with normal blood pressure:						
Prone .....	73	....	71	....	...	....
Standing .....	82	....	79	....	...	....
Average pulse rate of those with hypotension:						
Prone .....	72	....	72	....	...	....
Standing .....	86	....	84	....	...	....
Number with normal blood pressure	66	....	20	....	...	....
Hypotensives:						
Number with low systolic only	77	....	2	....	...	....
Number with low diastolic only	19	....	19	....	...	....
Number with both low sys- tolic and diastolic .....	18	....	4	....	...	....
Total hypotensives .....	48	42.1	25	55.5	73	45.9
Total crashes due to matériel failure	35	30.7	8	17.7	43	27.0
Total crashes due to personnel (pilot error) .....	79	69.3	37	82.2	116	73.0
Number of hypotensives in crashes due to matériel failure .....	8	7.0	3	6.6	11	6.9
Number of hypotensives involved in crashes due to personnel (pi- lot error) .....	*40	35.1	*22	48.8	62	39.0
Number with normal blood pres- sure involved in crashes due to personnel or pilot error .....	*28	14.5	*9	20.0	37	23.9

\*83.3% of all hypotensives.

\*88% of all hypotensives.

\*42.4% of those with normal blood pressure

\*45% of those with normal blood pressure.

Turning now to the table where a study was made of the students under instruction at a naval air station, it will be noted that out of the 45 case records studied, 25 (55.6 percent) showed some form of hypotension. Two showed a low systolic pressure with a normal diastolic,



19 showed a low diastolic only and 4 had both low systolic and diastolic. From these 25 hypotensives, 22 (88 percent) showed that the official cause of their crashes was due to personnel or pilot error. In the remaining 20 cases with normal blood pressure findings, there were 9 (45 percent) whose official report showed the cause of the crash to be due to pilot error.

Certain relationships as far as hypotension is concerned, may prove to be a problem worth considering in some of these fatal crashes. It would seem therefore from the above study, that hypotension points to a factor in fatal crashes due to pilot error.

The relationship of fatal crashes due to materiel failure and those due to pilot error is interesting. The ratio is about 1:3. Another factor noted in this series of cases was the higher average pulse rate, particularly the standing rate, among the hypotensives. This is in agreement with Treadgold's<sup>1</sup> observation in his so called non athletic group which he found to be poor aviation material. The average prone pulse rate for those with normal pressures averages about the same as that noted in the hypotensives, while the standing pulse rate in the hypotensives averages four beats in the seasoned pilots and five beats in the student pilots higher than those with normal blood pressures. This shows that the heart action in hypotensives is apparently more sensitive to mild exertion than in those with the normal blood pressure or else it is a manifestation of imperfect vasomotor control. It may be that these increased pulse rates are quantitative reactions modified by physiologic factors, that those with normal blood pressures have a better physiologic reserve of power to meet the average emergency without completely blowing up as it were, over trivial matters. Every flight surgeon has experienced this phenomena in the examining room. It appears that the hypotensive endeavors to react properly, but fails through lack of physiologic reserve, the blood pressure then falls and a concomitant increase in the heart rate occurs which is necessary to maintain the defense of the individual. He lacks the physiological equipment to carry out the required response or to react rapidly to stress.

It is realized that the number of cases studied here is too small to draw any but the most tentative conclusions. It is difficult to lay down in concrete terms the course to follow. That comes with a background of experience and further experimentation. There is no doubt that the emotional side plays an important part in cardiovascular stability. Then there is the fatigue factor. Psychological fitness is as important as physical fitness. No one factor alone can supply the answer to the problem of vasomotor or cardiovascular efficiency. All these various



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factors and combinations must be taken into account in estimating fitness for flight duty.

In the light of the present conflict and the part aviation is playing and the prominent place it will occupy in the future as an arm of our national defense, more study should be done on the significance of hypotension in selecting personnel for flying and in analysis of crashes.

### Summary

1. Hypotension is a rather relative term inasmuch as it has been more or less ill-defined. However, it may be said to exist when the systolic pressure is below 110 mm. Hg., or the diastolic below 70 mm Hg.

2. Hypotension may be compatible with a normal state of well-being and health, but, if persistent, careful study and caution should be exercised in qualifying these individuals for aviation training.

3. Hypotension may be associated with a momentary dizziness and a fall in the blood pressure to very low levels on assuming the erect posture. This should be a permanent disqualification for flying.

4. Persistent hypotension is not common and its incidence is difficult to estimate. It may not be permanent and it may be influenced by insidious disease or pathology. Occasional hypotension seems quite common in young individuals.

5. In 159 fatal crashes, 73 pilots (45.9 percent) manifested some form of hypotension. Of these 73 hypotensives, in 62 (85.6 percent) the official cause of fatal crash was stated to be due to error of the pilot.

6. Another noteworthy factor in this series of cases was the higher average pulse rate, particularly the standing rate, among hypotensives.

7. Ability of hypotensives to withstand centrifugal force depends upon the reaction of the vasomotor system, modified in some cases by an efficient physiologic reserve to maintain a nearly basic blood pressure and pulse to meet an emergency, be that a serious or harmless emotional situation. Furthermore, if continuous violent flying is indulged in over a long period of time this reserve can become exhausted due to fatigue and bring about a symptom complex similar to that seen in moderate and severe grades of hypotension with postural giddiness due probably to lessening of vasoconstrictor tone of the arterioles.

8. It seems reasonable, therefore, to conclude that the individual with a normal blood pressure would be better able to withstand continuous violent flying under combat condition over a longer period of time with less exhaustion and fatigue than the hypotensive. In other words he would be less apt to "go to pieces" or commit pilot error under stress.



9 From this study of 159 fatal crashes it appears that more attention should be given to hypotension and its significance in the selection of flying personnel as a further means of lowering crash hazards. If hypotension is present and the individual concerned is unable to increase the diastolic pressure above 70 mm Hg on standing, this should be taken as an unfavorable sign for aviation. A fall of, or only a meager rise of blood pressure on change from a prone to standing position shows vascular instability which should be carefully studied in selecting a pilot for military aviation.

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## THE MEDICAL ASPECTS OF DEEP SEA DIVING

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Classical historians record for us many stories of the employment of "naked" divers, even as early as 460 B.C. In the intervening centuries men have continued to dive to great depths without any type of suit and even today in many parts of the world similar practices are employed by those engaged as pearl and sponge divers. They have been able to dive to depths as great as 200 feet and to stay under the water for as long as 4 minutes  $46\frac{1}{4}$  seconds. However, according to Davis,<sup>1</sup> the average time is not more than  $1\frac{1}{2}$  minutes and the usual depth not more than 80 to 100 feet for most "naked" divers. Other than the obvious dangers from fish and giant clams the naked divers are exposed to the possibility of lung collapse when attempting great depths.

The diving dresses pictured in early histories appear amusing and more like Rube Goldberg inventions than any serious attempt to make under water work easier. It was not until 1857 that Siebe of England made a practical diving dress which has served as the model from which the modern diving dress has been developed. With this new diving dress came deeper work for greatly extended periods of time and unfortunately, also, new physical hazards were encountered.

The most important of these is Compressed-Air Illness which has been variously called Caisson Disease, Bends, Aeropathy or Diver's Paralysis. The literature concerning this condition is extensive,<sup>2</sup> but for the purpose of this discussion only a brief description will be given. The condition was first accurately described in 1845 although symptoms were noted as early as 1820. There were many and varied hypotheses presented as to the cause but none of them has stood the test of time except the gaseous emboli theory. This theory is based on the fact that as the individual breathes compressed air, whether it be in a diving suit, bell, caisson, or tunnel, the blood circulating through the lungs is exposed to a partial pressure of nitrogen and oxygen proportional to the air pressure, and takes up an extra amount of nitrogen and oxygen proportional to this increased pressure. As the blood circulates through the body the extra oxygen is used by the tissues but the extra nitrogen is not used, and gradually saturates all of the tissues until they are charged with nitrogen at the partial pressure existing in the air breathed. It is evident at once that there are two factors involved in this saturation, namely, the depth or degree of pressure and the length of time exposed to this pressure.



If the air pressure is lowered slowly (decompression) then the process is reversed and the nitrogen is given off through the lungs and equilibrium again established with atmospheric air pressure. But if decompression is too rapid the blood and tissues, which are supersaturated with nitrogen are left with an internal partial pressure far above the external atmospheric partial pressure. Under these conditions the nitrogen tends to leave the blood and tissues in bubble form and produce local or general blockage of the circulation or they may produce painful pressure or tearing of the tissues. The symptoms of the illness vary according to the location of these bubbles and the local tissue damage produced.

Thus we have three principal factors involved in the production of compressed air illness: degree of air pressure to which exposed, length of time exposed to this pressure and the length of time taken to come out from this pressure to atmospheric pressure. In addition to these we have certain physical predispositions having a secondary bearing on the production of the illness which are age, systemic disease, degree of fatness, alcoholic consumption and fatigue or general malaise.

Since the pressure of free gas in the blood or tissue fluids is the cause of the illness, it is evident that the variety and severity of the symptoms will depend upon the location of the gas set free and, the volume of this free gas. Thus, unconsciousness, collapse and early death may result from emboli in the pulmonary or coronary arteries, or in the vessels supplying the vital centers of the brain. Pain may result from bubble formation in any unyielding tissue such as ligaments, fascia, periosteum, muscle spindles, or nerve sheaths. Air embolism either of the vessels or white matter of the spinal cord may cause paraplegia, while involvement of the cerebral vessels or tissues may lead to monoplegia, hemiplegia, aphasia, or sensory paralytic symptoms. Symptoms rarely develop from bubbles in the liver, spleen, kidneys, adipose tissue or veins. These silent areas far outnumber the painful areas which in turn outnumber the vital areas, so except in cases of massive bubbling the chances of serious involvement are slight.

The treatment for this condition may be summarized by saying that the patient must be immediately placed under increased air pressure and that this pressure should be carried to at least the pressure of the original exposure that this pressure should be maintained until symptoms disappear or for a minimum of 30 minutes or a maximum of 2 hours and that the return to atmospheric pressure (treatment decompression) should be much slower than the original return to atmospheric pressure. Oxygen or helium oxygen mixture should be breathed during this de-



compression and massage, exercise and nursing care given as indicated.

Since, as pointed out earlier, the cause is the failure to properly eliminate the excess nitrogen, it then follows that prophylaxis depends upon the proper return to atmospheric pressure which process we call decompression. The exact computation of the length of decompression necessary depends upon the length of time exposed and the depth of the exposure, and is based upon physiological factors of saturation and desaturation times of various tissues. Tables have been prepared and prescribed for the divers in the U. S. Navy and for compressed air workers in various States.

One of the greatest difficulties experienced by those going under pressure is difficulty in clearing the ears or in equalizing the pressure through the Eustachian tubes so that it will be the same on both sides of the drum. Thus it is immediately seen that acute upper respiratory infections at once eliminate men from taking pressure. Much has been written concerning the damage to ears when trying to take pressure and the author frequently sees ear drums that have been severely damaged, even ruptured, by ill advised attempts to force the ears in trying to take pressure.

Perhaps the most interesting effect of high pressure air is that upon the mental and neuromuscular responses of those exposed. They have a definite feeling of stimulation which they liken to a feeling of "drunkenness." In spite of exaggerated confidence in their ability accomplishment falls far short of that demonstrated at atmospheric pressure. This was noted by Phillips<sup>3</sup> who found it associated with emotional disturbances, and ascribed the condition to psychological changes. Others reported such changes and attributed them to "the narcotic effect of the increased nitrogen tension." Practically it has been demonstrated many times that there is an appreciable decrease in mental ability, characterized by increased difficulty in the assimilation of facts and in the making of quick and accurate decisions. This mental sluggishness may be ascribed to the slowing process of cerebration.

Also there is a lengthening of the reaction time and a loss in neuromuscular control and response. Data were presented by Shilling and Willgrube<sup>4</sup> which actually measured these changes and proved quantitatively the accuracy of the experimental deductions. The real importance of this condition is seen when it is realized that the limiting factor on the depth to which a man can go is found in this field and in no other. This was illustrated during the Rescue and Salvage operations on the U.S.S. *Squalus* where much difficulty was experienced with the divers: one master diver with wide experience began calling football signals



from the deck of the sunken submarine and he had to be brought to the surface at once, another diver lost consciousness completely and had to be brought up the descending line by his diving partner, still another man was trying to cut his own life line and air hose when he was taken in hand. The limiting depth for most divers breathing air is about 300 to 320 feet for any practical work. Certain other physiological changes occur such as slowing of the pulse rate, lowering of the systolic blood pressure and lessening of the pulse pressure, lessening of the blood circulation time changes in the blood chemistry, and loss of cardiac efficiency but they do not assume the importance of the mental and neuromuscular changes although they may be contributing factors.

The most spectacular recent development in deep sea diving is the adoption of a mixture of helium and oxygen as a substitute gas for air in very deep dives. Although helium was suggested as early as 1919 the first practical work for diving was done during the salvage of the *Squalus*. In this connection Behnke and Willmon<sup>5</sup> say. In contrast with previous diving methods the distinguishing features of the diving technic were the successful employment of helium oxygen mixtures for deep diving in cold water made necessary by the failure of the standard method of using air.

The interval between the first suggestion in 1919 and the successful use of helium oxygen in diving on the *Squalus* in 1939 was not bridged in one stride for during this time experimental work was done which established the following facts that helium was colorless, odorless, tasteless, physiologically and chemically inert, that it can be liquified and solidified and has a density one seventh that of nitrogen and one eighth that of oxygen, that its solubility in water and serum under standard conditions is a little over one half that of nitrogen and that its solubility under pressure is directly proportional to the pressure of the gas according to Henry's law, that it has much greater diffusibility than other gases and therefore less effort is required to move it through semi permeable membranes and narrow orifices that mixtures of helium and oxygen could be breathed by men and animals at atmospheric pressure for extended periods without harm and that breathed under increased pressures it caused no untoward physiological changes.

These properties led to its trial in medical conditions where a mixture of 80% Helium—20% Oxygen proved of value in the treatment of such conditions as asthma, emphysema, obstructive lesions of the trachea, larynx and bronchi, pneumonia and cardiac decompensation. It has also been used as a diluent and vehicle in the giving of gas anesthesia.



## *The Medical Aspects of Deep Sea Diving*

The rationale for the use of helium-oxygen mixtures in diving is that helium has the advantage of being less soluble than nitrogen and also that it diffuses more rapidly in the body fluids and tissues which results in more rapid elimination of the gas from the body during decompression. Thus decompression time can safely be shortened without danger of developing the "Bends." The mixture could also be breathed following a dive thus facilitating the elimination of nitrogen and shortening materially the time necessary for decompression.

However, the most important consideration in the use of helium-oxygen mixtures for diving is that, as reported by End,<sup>6</sup> it lessens and in some cases eliminates the untoward mental and neuromuscular symptoms observed under increased air pressure. As noted earlier this change was demonstrated during the salvage of the U.S.S. Squalus.

Although much has been accomplished in the study of the medical aspects of deep sea diving there are still many problems unsolved which remain as a challenge to those who are interested and working in this field.

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# CASES OF INJURY TO THE VERTEBRAL OCCURRING IN THE ROYAL AIR FORCE

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The medical branch of the Royal Air Force has occasion to treat a large number of accident casualties in the course of routine duties, but it must not be assumed that these are usually associated with the practice of aviation. An aircraft accident may on occasion be appallingly destructive in its effects, yet it is surprising how much the human frame can tolerate and how often the pilot and occupants are relatively uninjured when the machine may be totally wrecked. Conversely, slight accidents may have tragic results through sheer misfortune. The cases that require prolonged treatment and study are those which are severely injured and yet survive the immediate effects of the crash. It is a limited class.

On the other hand, the Air Force consists of a rapidly increasing number of healthy individuals who are chiefly below 30 years of age, who are encouraged to lead an active life, and for whom there are opportunities to indulge in most forms of sport. In a study of vertebral injuries we find that the majority of the cases which come under the care of the Air Force surgeons are the result of every day life, as opposed to flying.

It is very difficult to draw any conclusions as to whether there are essential underlying differences between the types of injuries received in flying accidents and those which occur as the result of other types of accidents. One interesting fact revealed itself in our survey of these cases—the high proportion of completely satisfactory results in pilots and airmen, so that they have eventually returned to full Air Force duty.

In the case of the flying personnel there is a special significance when it is appreciated that in the United Kingdom pilots of Service and commercial aircraft require to be passed medically fit by the Central Medical Establishment of the Air Ministry. Only after an exhaustive medical examination are pilots graded as physically fit for full flying duties, for there is a definite duty to safeguard the occupants of aircraft and the general public by eliminating the unfit pilot. The surgeon's concern is chiefly that of the function of the limbs and, with the neurologist, to ensure that movements are co-ordinated. Consideration has to be given to the necessity that function shall be correct under the



## *A Review of Cases of Injury to the Vertebrae Occurring in the R. A. F.*

stresses imposed by flying, such as those due to increases of "gravity" and height and to the sitting for long periods in relatively cramped positions. A high level of efficiency has to be maintained, and it is significant that of the very small number of cases we are able to quote the majority were ultimately passed fit for flying duties. Little more than a decade ago such cases would probably have been condemned to be cripples for life. Now, despite the fact that we cannot claim to be dogmatic on such slender evidence, it would appear that they have a reasonable opportunity of achieving this high standard of physical fitness.

### **Analysis of Case Records\***

A search was made through the records of the last five years for cases which had received treatment for injuries to the vertebral column. We are able to trace fifty-seven such cases, but are unable to state that these represent all those which have occurred during this period, although none has been omitted to our knowledge. Of this total nine were the result of flying accidents, and the remainder were the result of non-flying accidents such as might occur in ordinary civil life. Of the flying personnel categorized as pilots, sixteen were injured; but of these only seven received their injuries in accidents to aircraft. Injuries received in aircraft accidents in all cases involved fractures of the bodies of the vertebrae, whereas other accidents gave rise to various types of injuries.

### **Flying Accidents**

There follow a record (Table I) and a summary of flying accidents to pilots and non-pilots:

#### **Non-flying Accidents (Pilots)**

Details of the non-flying accidents occurring to pilots are given in Table II; these are followed by a summary of the cases.

#### **Non-flying Accidents (Non-pilots)**

It is not proposed to go in any great detail into the injuries arising out of the pursuit of a non-flying occupation affecting the personnel of the Service who are not categorized as to their fitness for flying duties, as these show no points of interest which differ from such cases occurring in civil life.

\* In the tables and case summaries the following abbreviations have been observed: A1—Fit for full flying duties. A2—Fit for limited flying duties. A3—Fit as combatant passenger in aircraft. A4—Fit as non-combatant passengers in aircraft. B—Fit for ground duties. t—Temporarily unfit. p—Permanently unfit. h—Fit for duties at home only.



TABLE I—Flying Accidents

Case No	Age	Occupation at Time of Accident	Site of Vertebral Injury	Type of Vertebral Injury	Injury to Cord, Paralysis, etc.	Treatment by Hyperextension	Medical Category on Discharge from Hospital	Time after Accident (Months)	Recent Medical Category	Time after Accident (Years)	Remarks
1	18	Pilot	C 7	Fr dis	++	Yes	Ap Bp	7	—	—	Physiological transection of cord
2	23	"	L 2	Comp fr	No	"	A1h Bh	6	A1B	6	Ambulant after fourteen days
3	22	Air gunner	L 2	" "	"	"	A1B	9	A1B	2½	Plaster retained for six months
4	24	Pilot	D 4	Slight comp fr	"	No	A2h Bh 10 000 ft	7	A1B	4	No paralysis. Some muscular wasting and "adipica"
5	23	"	D 3, 4, and 5	Comp fr	"	Yes	A4h Bh	3	A1h, Bh	2	Ambulant after four days
6	30	Passenger	D 11	" "	"	"	Fit for duty	6	—	—	Started limited flying after twelve months
7	23	"	L 4 and 12	"	"	"	"	4	—	—	Slight muscular weakness noted in early stages (non-pilot)
8	—	"	L 4 and 12	Comp fr.	"	"	Invalided	—	—	—	Fracture of body of L 5 and ala of sacrum
9	—	Pilot	L 1	" "	"	"	A1B	—	—	—	Plaster worn for six weeks Resulted in gross deformity

*Summary of Flying Accidents*—Fractures of bodies of vertebrae, 9 (A1B, 4; A1h Bh, 1; fit for duty, 2; died, 1; invalided, 1.) There were no other vertebral injuries.



TABLE II.—*Non-flying Accidents (Pilots)*

Case No.	Age	Type of Accident	Site of Vertebral Injury	Type of Vertebral Injury	Injury to Cord, Paralysis, etc.	Treatment by Hyperextension	Medical Category on Discharge from Hospital	Time after Accident (Months)	Recent Medical Category	Time after Accident (Years)	Remarks
1	24	Hunting	C. 5	Dislocation	No	Yes	A4h Bh A1B	14	A1B	2	Hyperextension, etc., failed to reduce. Spinal fusion performed. A1B seven months later
2	20	Car	L. 1 and 2	Comp fr.	"	"	A4h Bh A1B	17	A1B	2	
3	31	Fell from window	D. 8	"	"	"	A1B	20	—	—	
4	23	Car	L. 2	"	"	"	A1B	7	—	—	
5	27	Fell 13 ft.	L. 2	"	"	"	A1B	3	—	—	Anterior portion of body of L. 2 fractured. Recumbent for two months
6	—	Kick at football	L. 2 and 3	Trans. proc.	"	No	A1B	14	—	—	Reduction incomplete. Ambulant with support two months after accident
7	24	Car	L. 1	Comp. fr.	Yes	Yes	Invalided	after 5 months	—	—	Slight displacement. Hyperextension performed four days after accident. Improved
8	—	Fall	L. 1, 2, and 3	Trans. proc.	No	No	A1B	1	—	—	Disposal uncertain. Thirsty six days in hospital
9	—	Cycle fall	L. 1	"	"	"	?	—	—	—	

*Summary of Non-flying Accidents (Pilots).—*Body of vertebrae, 5 (A1B, 4; invalided, 1). Dislocation, 1 (A1B, 1). Other injuries to vertebrae, 3 (A1B, 2; uncertain, 1).